Ecosystem Health

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Canadian Soil Quality Guidelines for the Protection of Environmental and Human Health: Toluene, Ethylbenzene and Xylenes (TEX)

Report No. 1-9

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This particular issue provides the background information and rationale for the development of Canadian Environmental and Human Health Soil Quality Guidelines for toluene, ethylbenzene and xylenes (TEX). For additional technical information regarding these guidelines, please contact:

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The Canadian Soil Quality Guidelines for toluene, ethylbenzene and xylenes (TEX) have been developed by the Soil Quality Guidelines Task Group of the Canadian Council of Ministers of the Environment (CCME). Environment Canada is both a member and the technical secretariat to this Task Group. These guidelines are included in the 2004 update to *Canadian Environmental Quality Guidelines*, which was originally published by the CCME in 1999. For CCME publications, please contact:

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This scientific supporting document is available in English only. Ce document scientifique du soutien n'est disponible qu'en anglais avec un résumé en français. Un sommaire de cette information technique est disponible en français sous le titre *Recommandations canadiennes pour la qualité de l'environnement* (CCME 1999).

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ABSTRACT

This scientific supporting document provides the background information and rationale for the derivation of Canadian Soil Quality Guidelines for toluene, ethylbenzene and xylenes (TEX) for the protection of environmental and human health. Guidelines for these substances were originally published in 1999 by the Canadian Council of Ministers of the Environment (CCME) in *Canadian Environmental Quality Guidelines*. The TEX soil quality guidelines have since been revised to reflect new data and lessons learned during the development of the Canada-wide Standard for Petroleum Hydrocarbons in Soil (CCME 2000).

This document contains a review of information on the chemical and physical properties of toluene, ethylbenzene and xylenes (TEX), a review of sources and emissions in Canada, the distribution and behaviour of TEX in the environment, and the toxicological effects of TEX on microbial processes, plants, animals and humans. This information is used to derive soil quality guidelines for TEX to protect both humans and ecological receptors in four types of land uses: agricultural, residential/parkland, commercial, and industrial. Development of these guidelines incorporated various modifications to the 1996 protocol (CCME 1996) that were used in the Canada-wide Standard for Petroleum Hydrocarbons in Soil (CCME 2000). These modifications included the derivation of guidelines for different soil textures (coarse and fine) and depths (surface soil and subsoil).

The Canadian Soil Quality Guidelines for the protection of environmental and human health for toluene, ethylbenzene and xylenes in coarse and fine soils on all land uses, as recommended by the Canadian Council of Ministers of the Environment are presented below.

Canadian soil quality guidelines for toluene, ethylbenzene and xylenes (mg·kg^{-1}). Values for coarse and fine soil represent the values for all land uses in both surface soil and subsoil.

	Coarse soil	Fine soil
Toluene	0.37	0.08
Ethylbenzene	0.082	0.018
Xylenes	11	2.4

RESUMÉ

Ce document scientifique justificatif présente une information de base ainsi qu'une analyse raisonnée pour l'élaboration des Recommandations canadiennes pour la qualité des sols concernant le toluène, l'éthylbenzène et les xylènes (TEX) en vue de la protection de l'environnement et de la santé humaine. Les recommandations relatives à ces substances furent d'abord publiées en 1999 par le Conseil canadien des ministres de l'environnement (CCME) dans les *Recommandations canadiennes pour la qualité de l'environnement*. Elles ont par la suite été révisées afin de refléter l'ensemble des nouvelles données et leçons apprises au cours du développement des Standards pancanadiens relatifs aux hydrocarbures pétroliers dans le sol (CCME 2000).

Ce document contient une revue de l'information sur les propriétés chimiques et physiques des TEX, une revue des sources et émissions au Canada, la distribution, le comportement dans l'environnement et les effets toxicologiques des TEX sur les processus microbiens, les plantes, les animaux et les humains. Cette information est utilisée pour l'élaboration des recommandations pour la qualité des sols relatives au toluène, à l'éthylbenzène et aux xylènes afin de protéger les récepteurs humains et écologiques dans quatre types d'utilisations des sols: agricole, résidentielle/parc, commerciale et industrielle. Plusieurs modifications du protocole de 1996 (CCME 1996) ont été incorporées à l'élaboration des nouvelles recommandations. Ces modifications incluent la dérivation de recommandations pour différentes profondeurs (surface et sous-sol) et textures due sol (grossier et fin).

Les recommandations canadiennes pour la qualité des sols en vue de la protection de l'environnement et de la santé humaine relatives au toluène, éthylbenzène et xylènes, telles que recommandées par le conseil canadien des ministres de l'environnement, pour les sols grossiers et fins pour les quatre types d 'utilisations des sols, sont présentées ci-dessous.

Recommandations canandiennes pour la qualité des sols pour le toluène, l'éthylbenzène et les xylènes (mg·kg^{-1}). Les valeurs pour les sols grossiers et fins représentent les valeurs pour le sol de surface ou le sous-sol et les quatre types d'utilisation des sols.

	Sols grossiers	Sols fins
Toluène	0,37	0,08
Éthylbenzène	0,082	0,018
Xylènes	11	2,4

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This scientific supporting document for the development of Canadian Soil Quality Guidelines for toluene, ethylbenzene and xylenes was prepared by Kelly Potter of the National Guidelines and Standards Office, Water Policy and Coordination Directorate of Environment Canada. It has been adapted from the 1999 supporting document for toluene, ethylbenzene and xylenes (Environment Canada 1999) and from a report prepared by Komex International Ltd. for the Canadian Council of Ministers of the Environment (Komex 2002). Individuals involved in the preparation of the two source documents from which this document was adapted include: Marie-Chantal Bertrand, Mark Bonnell, Doug Bright, Glen Cain, Sylvie Coad, Philippa Cureton, Kristina Curren, Pam Dilworth-Christie, Ruth Fawcett, Christian Gagnon, Raju Gangaraju, Connie Gaudet, Carmela Grande, Victoria Laube, Luke Levesque, Jason Lin, Mike McFarlane, Heather McMurter, Stephanie Meakin, Vincent Mercier, Deborah Milne, Julian Moffat, Daniel Nadon, Stacey Norris, Sylvain Ouellet, Tracy Schneider, James Sevigny, Sherri Smith, Scott Teed and Miles Tindal. Technical assistance with this document was provided by Brigitte Lavallée.

This document incorporates review comments received from various scientists representing federal and provincial government organizations, academic institutions, and the private sector. Thanks are extended to all those who provided input. In particular, the members of the CCME Soil Quality Guidelines Task Group are gratefully acknowledged for their scientific advice and reviews.

CHAPTER 1. INTRODUCTION

Canadian Environmental Quality Guidelines are intended to protect, sustain, and enhance the quality of the Canadian environment and its many beneficial uses. They are generic numerical concentrations or narrative statements that specify levels of toxic substances or other parameters in the ambient environment that are recommended to protect and maintain wildlife and/or the specified uses of water, sediment, and soil. These values are nationally endorsed through the Canadian Council of Ministers of the Environment (CCME) and are recommended for toxic substances and other parameters (e.g., nutrients, pH) of concern in the ambient environment.

The development of Canadian Soil Quality Guidelines was initiated through the National Contaminated Sites Remediation Program (NCSRP) in 1991 by the CCME Subcommittee on Environmental Quality Criteria for Contaminated Sites. In response to the urgent need to begin remediation of high priority "orphan" contaminated sites, an interim set of soil quality criteria was adopted from values that were in use in various jurisdictions across Canada (CCME 1991). Although the NCSRP program officially ended in March of 1995, the development of soil quality guidelines was pursued under the direction of the CCME Soil Quality Guidelines Task Group because of the continued need for national soil quality guidelines for the management of soil quality (with a particular focus on remediation of contaminated sites). Environment Canada serves as the technical secretariat to this Task Group.

Canadian Soil Quality Guidelines are developed according to procedures that have been described by the CCME (CCME 1996, 1997, and reprinted in 1999). According to this protocol, both environmental and human health soil quality guidelines are developed for four land uses: agricultural, residential/parkland, commercial, and industrial. The lowest value generated by the two approaches for each of the four land uses is recommended by the CCME as the Canadian Soil Quality Guideline. Guidelines for a number of substances were developed using this protocol and released in a working document entitled *Recommended Canadian Soil Quality Guidelines* (CCME 1997). The guidelines originally published in that document have since been revised and are now superseded by the Canadian Soil Quality Guidelines for the protection of environmental and human health published by the CCME in October of 1999 (CCME 1999). The interim soil quality criteria (CCME 1991) should be used only when soil quality guidelines based on the CCME protocol have not yet been developed for a given chemical.

This scientific supporting document provides the background information and rationale for the derivation of soil quality guidelines for toluene, ethylbenzene and xylenes (TEX). This document contains a review of information on the chemical and physical properties of these chemicals, a review of sources and emissions in Canada, the distribution and behaviour of TEX in the environment, and the toxicological effects of TEX on microbial processes, plants, animals, and humans. In addition, the chapters describing the derivation of the environmental and human health soil quality guidelines for TEX includes revisions made in 2002-2003 to the guidelines that were released in 1999 (CCME 1999). The revised recommended Canadian Soil Quality Guidelines for the protection of environmental and human health are also presented.

The Canadian Soil Quality Guidelines presented in this document are intended as general guidance. Site-specific conditions should be considered in the application of these values. The reader is referred to CCME (1999) for further generic implementation guidance pertaining to the guidelines. Soil quality guidelines are derived to approximate a "no- to low" effect level (or threshold level) based only on the toxicological information and other scientific data (fate, behaviour, etc.) available for the substance of concern, and they do not consider socioeconomic, technological, or political factors. These non-scientific factors are to be considered by site managers at the site-specific level as part of the risk management process. Because these guidelines may be used and applied differently across provincial and territorial jurisdictions, the reader should consult the laws and regulations of the jurisdiction they are working within for applicable implementation procedures.

CHAPTER 2. BACKGROUND INFORMATION

Physical and Chemical Properties

Benzene, toluene, ethylbenzene and the three xylene isomers are monoaromatic hydrocarbons that are often studied together, being referred to as BTEX, since they are all present in gasoline and comprise more than 60% of the mass that goes into solution when gasoline contacts water (Brookman et al. 1985 as cited by Barbaro et al. 1992). Soil quality guidelines have already been derived for benzene (CCME 2004; Environment Canada 2005) and the data will not be reiterated here. Thus, the present document will focus on toluene, ethylbenzene and the three isomers of xylene, these isomers being *o*-, *m*-, and *p*-xylene, depending on the position of the methyl group on the benzene ring (1,2-, 1,3- and 1,4-, respectively).

Toluene, ethylbenzene and the three xylene isomers fall into the broad category of volatile organic compounds that are monoaromatic hydrocarbons composed of an alkyl-substituted benzene ring. All TEX compounds have significantly high vapour pressures and Henry's law constants. Hence, they are subject to rapid volatilization. They also have high air saturation potentials. These characteristics combined with their low flashpoint make them highly flammable. The solubilities of TEX in water are low, ranging from 122 to 707 $mg{\cdot}L^{-1}$, but are high enough to be of environmental concern. TEX have a low octanol/water partition coefficient ($\log K_{ow} < 4.0$), indicating a low fat solubility and consequently low bioaccumulation potential. Physical and chemical properties of TEX compounds are presented in Appendix I.

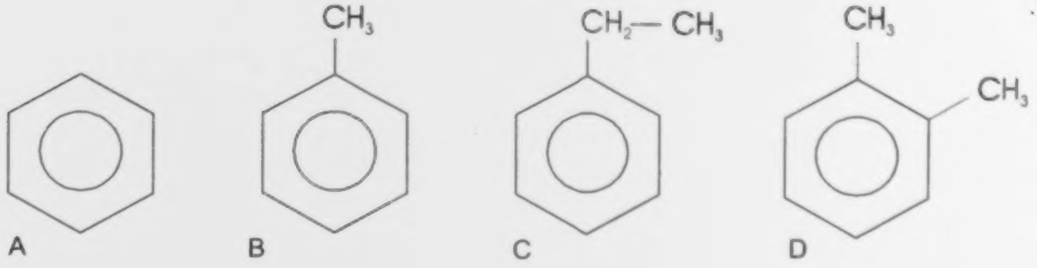

Figure 1. Chemical structure of (A) benzene, (B) toluene, (C) ethylbenzene and (D) o-xylene.

Analytical Methods

There are a number of analytical methods available for measuring TEX compounds in soils. The recommended methods, presented in Appendix II, are US EPA Method 8240B, Packed Column Technique and US EPA Method 8260A, Capillary Column technique both of which utilize Gas Chromatography/Mass Spectrometry (CCME 1993). Both techniques are applicable to nearly all sample types and can be adapted to measure either low or high concentrations.

The detection limit in soil for method 8240B is 5 $\mu g \cdot kg^{-1}$ for all three TEX compounds.

Production, Uses, and Sources

Total production capacity and supply of toluene and xylenes compounds in Canada are presented in Appendix III.

TEX compounds are produced as products or by-products in petroleum and coal refining. Toluene and xylenes are produced as an aromatic mixture with benzene, primarily from catalytic reformate in refineries and secondarily, as by-products of olefin manufacture during the cracking of hydrocarbons. Ethylbenzene is primarily produced by the alkylation of benzene with ethylene.

TEX compounds are widely used as solvents in paints, lacquers, adhesives, inks, cleaning and degreasing agents and in the production of dyes, perfumes, plastics, pharmaceuticals and pesticides. TEX compounds also comprise a significant fraction of crude petroleum. The typical fraction of TEX in the gasolines used in Ontario are 6.7, 1.4 and 6.9% in regular unleaded, and 11.3, 1.7 and 8.0% in premium unleaded for toluene, ethylbenzene and xylenes, respectively (OMOE 1993). Based on an average toluene content of 8.3% by weight, the gasolines sold annually in Canada contain some 2,000 kt of toluene, most of it being burned during normal engine operation (Madé 1991). The total yearly consumption of toluene in Canada, including both isolated toluene and toluene in gasoline, is estimated to be 2,263 kt.

The introduction of TEX into the atmosphere is due largely to incomplete combustion of TEX-containing petroleum fuels from motor vehicles, and volatilization of TEX based solvents and thinners. Other natural sources include volcanic gases, forest fires and vegetation (Isidorov et al. 1990).

TEX compounds are released to soil and water mainly from leaking of underground petroleum storage tanks and landfill sites, accidents and spills during transportation, pesticide applications, and discharges of industrial and municipal wastes (Bobra 1991; DGAIS 1992; Johnson et al. 1989; Lesage et al. 1990 and 1991).

Levels in the Canadian Environment

The concentrations of TEX compounds found in various compartments of the Canadian environment are discussed below.

Soil

Level III fugacity model, with air, water, soil and sediment compartments at steady state, predicts that from all TEX released into soil, 9.4%, 4.9% and 3.1% will be transferred to the atmosphere for toluene, ethylbenzene and xylenes respectively; less then 1% will be in water, less than 1% into sediments, and 89.4%, 94.7% and 96.5% will remain into the soil for toluene, ehtylbenzene and xylenes respectively (Mackay et al., 1992).

Data on concentrations of TEX compounds in soils and sediments are scarce for the Canadian environment. In Ontario, soil samples from undisturbed old urban and rural parklands not impacted by local point sources were analyzed by the Ontario Ministry of Environment and Energy for a variety of chemicals to determine average background concentrations known as "Ontario typical range" (OTR). The 98th percentile of this data distribution (OTR_{98}) may be considered as the background level, and corresponds, for samples taken from rural parkland, to 0.0013, 0.00046, and 0.00092 $mg \cdot kg^{-1}$ soil for toluene, ethylbenzene and total xylenes respectively (OMEE 1993).

Atmosphere

TEX discharged to the atmosphere has very little potential for entering other media. Level III fugacity model, with air, water, soil and sediment compartments, predicts that from all TEX released to the atmosphere, over 98% will remain in the atmosphere at steady state (Mackay et al., 1992).

Concentrations of TEX compounds in ambient air vary widely depending on the source and the sampling season. Toluene concentrations ranging from 1.1 $\mu g \cdot m^{-3}$ in rural areas (Dann et al. 1989) to 2600 $\mu g \cdot m^{-3}$ near gas stations in summer (PACE 1987, 1989) have been reported. Similarly, xylenes concentrations ranging from 0.3 $\mu g \cdot m^{-3}$ in rural areas (Dann and Wang 1992) to 22 000 $\mu g \cdot m^{-3}$ (Dann and Gonthier 1986) above landfill sites have been reported. Dann and Gonthier (1986) reported toluene concentrations in air columns of three drill holes to range from less than 2 $\mu g \cdot m^{-3}$ (detection limit) to 31 $mg \cdot m^{-3}$ in areas that received hazardous wastes in Quebec. Bruckmann et al. (1988) have reported ethylbenzene concentrations of 22.0 $\mu g \cdot m^{-3}$ were detected in an industrial/residential site near a rubber factory and of 10.8 $\mu g \cdot m^{-3}$ at an industrial site near refineries producing lubricating oil (annual means).

Water

In water, the reported toluene concentrations vary from 0.1 $\mu g \cdot L^{-1}$ (NAQUADAT 1992) to 0.5 $\mu g \cdot L^{-1}$ in Great Lakes (Otson 1987). Lesage et al. (1990) reported 3900 $\mu g \cdot L^{-1}$ of toluene in a shallow aquifer near a chemical waste disposal site at Elmira, Ontario. Xylene concentrations in water vary from 0.32 to 1.72 $\mu g \cdot L^{-1}$ across Canada (NAQUADAT 1992) and in sludge, 52 $\mu g \cdot L^{-1}$ for *o*-xylene and 1417 $\mu g \cdot L^{-1}$ for *m*- and *p*-xylene were reported (OMOE 1992).

Existing Criteria and Guidelines

Existing criteria and guidelines for the assessment and remediation of TEX contaminated soils are presented in Appendix V.

CHAPTER 3. ENVIRONMENTAL FATE AND BEHAVIOUR

Soil

The major processes that determine the behaviour of TEX in the terrestrial environment are volatilization, sorption, biodegradation and leaching. TEX compounds do not have hydrolysable groups and therefore, hydrolysis is not an important transformation pathway (Howard 1990). Likewise, TEX are not degraded directly by photolysis (Howard 1990; Mackay et al. 1992). In the atmosphere, however, TEX are degraded with a half-life of 3 h to 1 day by reacting with photochemically produced hydroxyl radicals.

Volatilization is the dominant process determining the fate of TEX in the terrestrial environment (Anderson et al. 1991; HSDB 1992; Jin and O'Connor 1990; Parker and Jenkins 1986). Volatilization depends on temperature, humidity, sorption and biodegradation processes in soils (Ashworth 1988; Aurelius and Brown 1987). The relatively high vapour pressures and Henry's Law Constants ($>10^{-3}$ $atm \cdot m^{3} \cdot mol^{-1}$) of TEX make them subject to rapid volatilization from soils with half-lives ranging from 2.2 to 28 d (Howard 1990; Anderson et al. 1991).

Adsorption reduces the mobility of TEX in soils and affects their biotransformation rate. Soil organic matter, especially humic acids, strongly sorb TEX compounds (Jin and O'Connor 1990; Jury et al. 1987; Schwarzenbach and Westall 1981; HSDB 1992; El-Dib et al. 1978). TEX compounds are also adsorbed on clay minerals such as bentonite, illite, and kaolinite. They follow Freundlich's adsorption isotherm (Kango and Quinn 1989; WHO 1985; Nielsen and Howe 1991; Crooks et al. 1993). Adsorption in soil increases with increasing TEX concentrations, with decreasing pH, and with decreasing moisture content (English and Loehr 1991; Chiou et al. 1981; Rutherford and Chiou 1992; HSDB 1992; El-Dib et al. 1978). Sorption is low in light textured soils with low organic matter (English and Loehr 1991; Garbarini and Lion 1986).

A variety of soil microorganisms are able to utilize TEX as a source of carbon, and degrade them to CO_2 and water. *Pseudomonas* species are the main degrading bacteria in soils but other species such as *Arthrobacter* have also been reported to degrade TEX compounds (Utkin et al. 1992). Intermediate degradation products for toluene are benzoic acid and 3-methylcatechol, while degradation of xylenes results in *m*-toluic, *p*-toluic and 2,3-dihydroxy-*p*-toluic acids (Nielsen and Howe 1991; Crooks et al. 1993). *O*-xylene was reported to be degraded at a significantly lower rate than the *m*- and *p*-isomers (Thomas et al. 1990). Degradation half-lives usually range from 5 to 10 days and are typically < 20 days (Mackay et al. 1992; Chiang et al. 1989; Evans et al. 1991a,b; Grbić-Galić and Vogel 1987; Haag et al. 1991). Degradation may occur in aerobic or anaerobic conditions. In aerobic conditions, the oxygen supply in soil is the major controlling factor (Allen 1991; Barker et al. 1989; Chiang et al. 1989). The availability of nutrients, especially nitrogen, also affects the degradation rate. This rate is higher in soil upper horizons and in unsaturated zones due to greater oxygen supply

(Haag et al. 1991; Miller et al. 1990; Kampbell et al.1987; Edwards et al. 1992). Anaerobic degradation is much slower and may be increased by adding nitrates and sulphates to the soil (Evans et al. 1991a,b; Edwards et al. 1992; Hutchins 1991; Beller et al. 1992).

TEX compounds are moderately soluble in water. Hence, they may move with percolating waters, either in solution or sorbed to dissolved organic mater. Thus, TEX compounds are moderately to highly mobile in soils (log K_{oc} 1.89 to 2.58 for toluene, 1.98 to 3.04 for ethylbenzene and 1.63 to 3.13 for xylenes, depending on soil) (Howard 1990; Mackay et al. 1992). In organic soils, TEX leaching is highest in low organic matter and light texture situations whereas in mineral soils, it depends on the type of clay and the soil moisture content. Sorption and biodegradation processes reduce TEX mobility in soils.

Water

Herman et al. (1991) examined the relationship between K_{ow}, bioconcentration, and toxicity of toluene, ethylbenzene, *m*-xylene, *o*-xylene, and *p*-xylene in algae (*Selenastrum capricornutum*). A strong positive linear relationship was reported between bioconcentration and K_{ow} ($r^2 = 0.98$), and between bioconcentration and toxicity (EC_{50}) ($r^2 = 0.99$). The sorption rate of these aromatic hydrocarbons by algae was initially rapid and then relatively constant. The 12 hours bioconcentration factors, expressed as logarithms to the base 10 were 1.99 for toluene, 2.31 for ethylbenzene, and 2.41, 2.40, and 2.34 for *m*-, *o*-, and *p*-xylene, respectively. The 8 day EC_{50}'s reported were 9.4 $mg{\cdot}L^{-1}$ for toluene, 4.8 $mg{\cdot}L^{-1}$ for ethylbenzene, and 4.4, 3.9, and 4.2 $mg{\cdot}L^{-1}$ for *m*-, *o*-, and *p*-xylene, respectively (Herman et al. 1991). Casserly *et al.* (1983) reported a higher BCF, i.e., 3.81, for toluene with *S. capricornutum*, whereas Geyer et al. (1984) reported 2.69 using *Chlorella fusca*.

Although TEX may accumulate in algae (Howard 1990), the relatively low log K_{ow} (< 4.0) of TEX compounds indicates that the bioconcentration potential is generally low (WHO 1985; Nielsen and Howe 1991).

CHAPTER 4. BEHAVIOUR AND EFFECTS IN BIOTA

The available information on the toxicological effects of toluene, ethylbenzene and xylenes on soil microbial processes, terrestrial plants and invertebrates, as well as mammals has been reviewed and summarized in this chapter in support of the derivation of environmental soil quality guidelines. This information has been tabulated in Appendices VI - XIV as either "consulted" studies (i.e., those studies which were reviewed but not used in the derivation of guidelines) or "selected" studies (i.e., those studies which met the screening procedures for use in the derivation of guidelines, as described in Chapter 6).

Soil Microbes

Anderson et al. (1991) reported that 100 $mg{\cdot}kg^{-1}$ soil dw of toluene or *p*-xylene was not toxic to soil microorganisms. Walton et al. (1989) observed depressed soil microbial activity, as measured by CO_2 production, at 1000 mg $toluene{\cdot}kg^{-1}$ soil dw. However, the effect disappeared 6 days after application suggesting low potential for long-term impacts. Hutchins et al. (1991) reported that *m*-xylene inhibited the rate of denitrification in soils in a Michigan aquifer.

Vonk et al. (1986) measured short-term (5 h) oxygen consumption, and nitrification in two soils (loam and humic sand), treated with toluene at 0, 300, 1000 and 10,000 $mg{\cdot}kg^{-1}$ soil ww. The NOEC values for respiration and nitrification were 300 to 1000, and <20 $mg{\cdot}kg^{-1}$ soil ww respectively and did not differ with the soil type. Slooff and Blokzijl (1988) reported that the NOEC for toluene on soil microbial respiration and ammonification ranged from 100 to 1300 $mg{\cdot}kg^{-1}$ while for nitrification, the NOEC was <26 $mg{\cdot}kg^{-1}$.

Eisman et al. (1991) studied the toxicity of a fuel mixture containing toluene, *o*-xylene, n-octane, cyclohexane, cyclohexene, benzene, and naphthalene using the Microtox assay (*Photobacterium phosphoreum*). The concentrations at which bioluminescence was decreased by 50% after an exposure of 5 min were 200 and 456 $\mu g{\cdot}L^{-1}$ for *o*-xylene and toluene, respectively. For the water-soluble fraction, the 5-min EC_{50} for *o*-xylene and toluene were 21 and 66 $\mu g{\cdot}L^{-1}$ respectively. Short-term volatility was not a factor as EC_{50}s were consistent for test periods that ranged from 2.5 to 15 min.

Terrestrial Plants

Summaries of the available consulted toxicological studies on the effects of toluene, ethylbenzene, and xylenes on terrestrial plants are presented in Appendices VI, VIII, and X, respectively. Plant toxicity studies selected for use in soil quality guidelines derivation are presented in Appendices XII, XIII and XIV.

Very little data were available on the uptake and toxicity of TEX to plants. Early work by a number of researchers indicated that concentrations of aromatic hydrocarbons in oils correlated positively with phytotoxicity (Havis 1950; Ivens 1952).

Ivens (1952) exposed detached leaves of runner bean and parsnip to toluene, ethylbenzene, *p*-xylene, and *m*-xylene vapour in a Bell jar for one hour and determined the degree of damage to the leaves. Phytotoxicity was found to be correlated with oils that had higher aromatic hydrocarbon content. This suggests that the volatile compounds could have a greater phytotoxic potential.

Toluene can enter the plant through the stomata and cuticle and thus damage the plasma membrane. Plant chlorosis and growth inhibition were induced at levels >6 $mg{\cdot}L^{-1}$ of air, 500 $mg{\cdot}L^{-1}$ of aqueous medium, and 1000 $mg{\cdot}kg^{-1}$ soil ww (Slooff and Blokzijl 1988).

Keymeulen et al. (1991) measured TEX concentrations in one and two year-old needles of six different Franco trees (*Pseudotsuga menziesii* Mirb.). Concentrations were greater in the two year-old needles. The same authors also measured TEX concentrations in leaves of six different "Skogholm" shrubs (*Cotoneaster dammeri* Schn.), concluding that the partitioning of monocyclic aromatic hydrocarbons into the plant cuticle depends on plant species, individual plant variation, amount of cuticle, and age of the leaves. Miller et al. (1976) maintained that there is no evidence that toluene is bioaccumulated in plant tissues in any quantity. No toxicological measurements were recorded in either of these studies.

Xylenes are selective herbicides used in carrot crops. They are also used for the control of submerged aquatic weeds. Bruns and Kelly (1974) applied xylenes to several field crops in irrigation water to assess injury to crops. The emulsified xylenes were applied at 370, 740 and 1480 $mg{\cdot}L^{-1}$ using an oscillating, half-circle sprinkler. No detectable symptoms of injury or reduction in yield were observed.

Environment Canada (1995) studied the effects of TEX on seedling emergence of radishes (*Raphanus sativus*) and lettuce (*Lactuca sativa*) in an artificial soil. For toluene, the NOEC, LOEC, EC_{25} and EC_{50} concentrations on seedling emergence were, for radishes, 6, 12, 7, and 84 $mg{\cdot}kg^{-1}$, respectively, and, for lettuce, 7, 17, 9 and 12 $mg{\cdot}kg^{-1}$ respectively (Appendix VI). For ethylbenzene, the corresponding toxicity values were 9, 20, 12 and 16 $mg{\cdot}kg^{-1}$ for radishes and 5, 9, 5 and 9 $mg{\cdot}kg^{-1}$ for lettuce, respectively (Appendix VIII). For xylenes, they were 1.4, 33, 32 and 97 $mg{\cdot}kg^{-1}$ for radish, and 0.6, 19, 5 and 13 $mg{\cdot}kg^{-1}$ for lettuce, respectively (Appendix X).

Root elongation studies for radishes and lettuce were conducted for TEX using nutrient solutions (Environment Canada 1995). The LOEC values for radishes were 15 $mg{\cdot}L^{-1}$ for toluene, 34 $mg{\cdot}L^{-1}$ for ethylbenzene, and 0.76 $mg{\cdot}L^{-1}$ for xylenes, respectively. For lettuce, in the same order, the LOEC values were 7 $mg{\cdot}L^{-1}$, 25 $mg{\cdot}L^{-1}$ and 0.52 $mg{\cdot}L^{-1}$.

Currier (1951) exposed tomato, carrot and barley seedlings to 12 $mg{\cdot}L^{-1}$ of toluene for 30 to 120 minutes at 25°C. Inhibition of root formation was found to be 0 to 75, 50 to

100, and 0 to 25 % for tomato, carrot and barley respectively. Hung (1992) reported erratic responses in seed mortality, germination and seedling vigour when seeds of corn were soaked in xylenes for up to 8 h.

With advanced techniques for determining the toxicity of highly volatile compounds, new plant toxicity tests were conducted by ESG International in 2002 (Appendices XII - XIV). Tests conducted with early northern wheatgrass (*Agropyron dasystachyum*) and alfalfa (*Medicago sativa*) examined the effects of TEX on shoot and root length and dry and wet biomass after 14 days of exposure in both coarse and fine soil. In coarse soils, the most sensitive endpoint for alfalfa was reduction of root dry mass with an IC_{25} value of 234 $mg{\cdot}kg^{-1}$ for toluene, 462 $mg{\cdot}kg^{-1}$ for ethylbenzene and 421 $mg{\cdot}kg^{-1}$ for xylenes. For the northern wheatgrass, the most sensitive endpoint was an IC_{25} for reduction of root dry mass, of 55 $mg{\cdot}kg^{-1}$ for toluene, 3 $mg{\cdot}kg^{-1}$ for ethylbenzene and 90 $mg{\cdot}kg^{-1}$ for xylenes (ESG 2002b). The results for fine soils reported by ESG (2002b) were recalculated by Komex (2002) to take into account volatile losses that occur between spiking the sample and introducing the plants 2 hours later (similar calculations had already been made by ESG for the data from the coarse soils). Therefore, the most sensitive estimated effect concentrations in fine soils for alfalfa and northern wheatgrass were an IC_{25} for reduction of root length, of 120 $mg{\cdot}kg^{-1}$ for toluene, 316 $mg{\cdot}kg^{-1}$ for ethylbenzene and 92 $mg{\cdot}kg^{-1}$ for xylenes. An IC_{25} for reduction of root wet mass for both plants were of 112 $mg{\cdot}kg^{-1}$ for toluene, 218 $mg{\cdot}kg^{-1}$ for ethylbenzene and 241 $mg{\cdot}kg^{-1}$ for xylenes (Komex 2002).

Terrestrial Invertebrates

Summaries of the available consulted toxicological studies of the effects of toluene, ethylbenzene, and xylenes on soil invertebrates are presented in Appendices VII, IX, and XI, respectively.

Environment Canada (1995) determined NOEC, LOEC, LC_{25} and LC_{50} values for survival of earthworms (*Eisenia foetida*) exposed to toluene, ethylbenzene and xylenes in artificial soil. The reported NOEC, LOEC, LC_{25} and LC_{50} values were 34, 71, 44, and 126 $mg{\cdot}kg^{-1}$ soil, respectively for toluene (Appendix VII); 73, 192, 113 and 155 $mg{\cdot}kg^{-1}$ soil, respectively for ethylbenzene (Appendix IX); and 33, 124, 56, and 79 $mg{\cdot}kg^{-1}$ soil, respectively for xylenes (Appendix XI).

The toxicity of toluene to *E. foetida* was also evaluated by Hartenstein (1982). Mortality and growth, measured as weight gain, were assessed at 2, 4, and 6 weeks after exposure to concentrations of toluene in the sludge, ranging between 0 and 4000 $mg{\cdot}kg^{-1}$ $bw{\cdot}d^{-1}$. Toluene caused 100% mortality at 2000 $mg{\cdot}kg^{-1}$ $bw{\cdot}d^{-1}$ and a reduced growth rate at <50 $mg{\cdot}kg^{-1}$ $bw{\cdot}d^{-1}$.

Neuhauser et al. (1985) exposed *E. foetida* to toluene and ethylbenzene on filter paper and reported 48-h LC_{50} values of 75 and 47 $\mu g{\cdot}cm^{-2}$, respectively. Slooff and Blokzijl (1988) reported a NOEC value of 15-50 mg $toluene{\cdot}kg^{-1}$ soil dw for *E. foetida*.

Vonk et al. (1986) exposed *Eisenia foetida* to 0, 32, 100, 180 and 320 mg toluene·kg^{-1} artificial soil. The 14-day and 28-day LC_{50} for mortality were reported between 100 and 180 mg·kg^{-1} soil ww. The 28-day NOEC for mortality was also reported in the same range. The 28-day NOEC for worms' appearance and for cocoon production were reported at concentrations between 10 to 32 and 32 to 100 mg toluene·kg^{-1} soil, respectively. The change in appearance was believed to be related to the ability of toluene to dissolve fat and damage cell membranes.

Studies commissioned by the CCME in 2001, and using advanced techniques for dealing with volatile compounds, examined the toxicity of TEX to the collembolan (*Onychiurus folsomi*) and the earthworm (*Eisenia andrei*) (Appendices XII to XIV). In coarse soils, the LC_{25}, for collembolans was 521 mg·kg^{-1}, 576 mg·kg^{-1} and 733 mg·kg^{-1}, for toluene, ethylbenzene and xylenes, respectively (ESG 2002b). The results reported by ESG (2002b) for fine soils were recalculated by Komex (2002) to take into account volatile losses that occur between spiking the sample and introducing the invertebrates 24 hours later (similar calculations had already been made by ESG for the data from the coarse soils). Therefore, in fine soils the LC_{25} for collembolans was 406 mg·kg^{-1}, 259 mg·kg^{-1} and 835 mg·kg^{-1} for toluene, ethylbenzene and xylenes, respectively (Komex 2002). NOEC and LOEC values of TEX for earthworms in coarse soils were 80 and 172 mg·kg^{-1} for toluene, 16 and 112 mg·kg^{-1} for ethylbenzene, and, 8 and 78 mg·kg^{-1} for xylenes (Appendices XII to XIV). In fine soils, earthworm NOEC and LOEC values were 172 and 368 mg·kg^{-1} for toluene, 16 and 112 mg·kg^{-1} for ethylbenzene, and 8 and 78 mg·kg^{-1} for xylenes.

Livestock and Wildlife

Studies specifically on the toxicological effects of TEX to livestock and wildlife are currently lacking.

CHAPTER 5. BEHAVIOUR AND EFFECTS IN HUMANS AND MAMMALIAN SPECIES

Uptake, Metabolism and Elimination

The uptake of TEX in animals may occur via many routes including oral, inhalation, subcutaneous, and dermal (percutaneous) absorption. TEX are absorbed and rapidly distributed throughout an animal's body. They are preferentially stored in adipose tissue, but are also accumulated in the kidneys, liver, and brain. Skowronski et al. (1989) found percutaneous absorption of toluene to be a major route of exposure in male rats. Excretion through urine is the major route of elimination (Chin et al. 1980; Mattia et al. 1991; Skowronski et al. 1989; Turkall et al. 1991).

Toluene

Following exposure via inhalation, Gospe Jr. and Calaban (1988) found toluene in the brain, as well as in the blood and liver. Distribution of toluene in the brain was found to be uneven (Ameno et al., 1992; Gospe Jr. and Calaban 1988) and not affected by methods of administration and blood concentration (Ameno et al. 1992). Toluene distribution in the brain was found to be correlated with local lipid concentrations (Ameno et al. 1992; Gospe Jr. and Calaban 1988). Lipid-rich areas of the brain, such as the medulla, are more likely to retain toluene. Intoxication of the medulla with toluene will affect certain functions, such as respiration (Guyton 1981).

Toluene administration increased liver cytochrome P_{450} levels in rats (Pyykkö et al. 1987) as well as free fatty acid (FFA) and triglyceride levels (Takahashi et al. 1988). An increase in FFA is a good indicator of stress in an organism. Increases in triglycerides may have an adverse effect on heart function. Long-term toluene exposure may result in increased liver fat due to the constant increases in systemic FFA and triglycerides (Takahashi et al. 1988).

Toluene is metabolized to benzyl alcohol via the cytochrome P_{450} mixed function oxidase system and is, in turn, oxidized to benzaldehyde. Benzaldehyde is subsequently oxidized to benzoic acid which is conjugated to form the major urinary metabolite, hippuric acid (Mattia et al. 1991; Skowronski et al. 1989). Small amounts of benzyl alcohol and ortho- and para-cresol can also be recovered from the urine of rats exposed to toluene (Skowronski et al. 1989). Reactive metabolites, formed in the liver of rats, bind irreversibly and covalently to microsomal detoxification components inactivating them permanently (Pathiratne et al. 1986). Inactivation may lead to increased toxicity of other xenobiotics.

Turkall et al. (1991) administered toluene, directly and mixed with soil, by gavage to rats. The soil types used were sandy (2% clay) and clay (22% clay). Toluene absorption in the stomach was reduced when administered with clay soil. However, metabolism and tissue distribution were unaffected by soil type.

Ethylbenzene

Chin et al. (1980a) reported that 44% of inhaled ethylbenzene was retained in the rat. Excretion was virtually complete within 42 h after exposure, with 82.6% in urine and 8.2% in expired gases. The main metabolites of ethylbenzene in the urine are hippuric acid (Chin et al. 1980b) and mandelic acid (Drummond et al. 1989).

Xylenes

Acute exposure to xylenes affects the cytochrome P_{450} system. Simmons et al. (1991) found that the concentration of rat hepatic cytochrome P_{450} increased significantly during acute (6 h) and short-term (3 d, 6 $h \cdot d^{-1}$) exposure to mixed xylenes up to 2000 ppm. Rat liver weight and size increased concurrently with the increase in cytochrome P_{450} and all increases were found to be readily reversible upon cessation of exposure (Simmons et al. 1991).

Elovaara (1982) found similar effects on the liver and kidney of the rat when exposed to *m*-xylene. A dose-dependent relationship was reported between xylenes concentration and changes in microsomal enzyme (cytochrome P_{450}) activity. Xylenes were found to be an effective inducer of rat liver oxidative metabolism even at low concentrations and with intermittent modes of inhalation exposure (Liira et al. 1991).

Toxicity

Summaries of the available consulted toxicological studies on toluene, ethylbenzene, and xylenes are found in Appendices VI - XI, respectively.

The acute toxicity of toluene to terrestrial animals via the oral, inhalation and dermal routes, is relatively low (OMOE 1989). Acute oral LD_{50} for toluene to young adult rats ranged from 5.55 to 6.6 $g \cdot kg^{-1}$ bw (Kimura et al. 1971; Smyth Jr. et al. 1969). Four-hour inhalation studies using rats gave an LC_{50} in the order of 8800 ppm in air (35 $mg \cdot L^{-1}$) (Carpenter et al. 1976), while a dermal toxicity test on rabbits resulted in an LD_{50} of 14,000 $mg \cdot kg^{-1}$ bw (Union Carbide 1976). Although dose levels are used as indicators of toxicity, biological effects of toluene exposure are reported to be more closely related to blood or tissue concentration (Moser and Balster 1985; Kishi et al. 1988).

One of the major effects of TEX compounds appears to be on the cytochrome P_{450} enzyme system, which is responsible for the metabolic detoxification of xenobiotics. Toluene inhibited the cytochrome P_{450} mixed function oxidase in the lungs of rats (Pyykkö et al. 1987). The detoxification of benzo[a]pyrene (BaP), a known carcinogen, is significantly reduced following acute *p*-xylene exposure (Roberts et al. 1986; 1988) and acute *m*-xylene exposure (Stickney et al. 1989). This inhibition of BaP metabolism is directly related to the reduction in cytochrome P_{450} (Stickney et al. 1989; Roberts et al. 1986; 1988) and possibly to an alteration in the phospholipid microenvironment of the cytochrome P_{450} (Roberts et al. 1988). Stickney et al. (1989) suggested that the inhibition of detoxification of xenobiotics, which also occurs in the presence of xylene, is due to irreversible binding of cytochrome P_{450}. Roberts et al. (1986) found that inhibition of xenobiotic metabolism by xylenes was directly dose and time-dependent. The reduction of cytochrome P_{450} metabolizing enzymes may result in increased toxicity of other xenobiotics (Furman et al. 1991). For example, in the case of BaP, the longer it stays in the body, the higher the probability that carcinogenic events will occur. Thus the presence of toluene may exacerbate the carcinogenic effects of BaP (Furman et al. 1991). Toluene and BaP may co-occur in the environment.

TEX compounds have been reported to affect the central nervous system of organisms. Acute toluene exposure may result in respiratory failure due to severe depression of the central nervous system (Moser and Balster 1985). Kishi et al. (1988) reported that the neurobehavioural effects of acute toluene inhalation depend on exposure concentrations. Rats showed a decrease in effective avoidance response rate of electric shock as the toluene concentration increased from 125 to 1000 ppm. At 2000 ppm, rats showed extreme excitation. At 4000 ppm, rats displayed a drastic increase in response rate, which gradually decreased to a light ataxia (failure or irregularity in muscle action/coordination). Kishi et al. (1988) confirmed the central nervous system as the organ most sensitive to toluene exposure and concluded that blood toluene levels are a reasonable index of the behavioural effects of toluene in experimental mammals.

Toluene

Subacute toxicity studies have shown that inhalation exposure to toluene affects locomotor function in rats and mice. Von Euler et al. (1991) exposed rats to 30 to 80 ppm toluene for 3 days, 6 hours per day, and found changes in locomotor behaviour in the case of rats with previously activated or sensitized dopamine receptors, hence suggesting that, at low concentrations, toluene is not the direct affector, but does have neural effects if receptors have been previously induced. Wood and Colotla (1990) exposed mice to toluene at different concentrations in 1-hour sessions twice a week for three weeks. At 300 ppm, no altered activity was noted. Motor activity increased at toluene concentrations of 560 to 1780 ppm and then decreased at exposure levels of 1780 to 3000 ppm.

Chronic inhalation exposure to toluene resulted in decreased body and brain weights of rats exposed to 320 $mg \cdot kg^{-1}$ bw (1400 $mg \cdot m^{-3}$) continuously for 30 days (Kyrklund et al. 1987). Phospholipid content in the cerebral cortex decreased, and general brain atrophy was noted, especially in the cerebral cortex. A distinct loss of grey matter suggests specific neurotoxic properties of toluene. Gospe Jr. and Calaban (1988) reported that toluene exposure leads to chronic neurological effects, which may result in irreversible dysfunction of certain CNS regions. Ladefoged et al. (1991) reported no central nervous system-neurotoxicity and no adverse effects on the liver or kidneys in rats when they were exposed to 0, 500 and 1500 ppm toluene for 6 hours/day, five days/week for 6 months. However, minor changes in the size of the cerebral cortex and amine content indicated certain irreversible effects of toluene.

Huff (1990) reported a LOEL of 375 $mg \cdot m^{-3}$, which induced a decrease in body weight (7.5 and 12 % in males and females, respectively), in a 14-week toluene inhalation study on mice and rats. In subchronic studies, a NOEL of 100 $mg{\cdot}kg^{-1}$ (375 $mg{\cdot}m^{-3}$) was reported for rats and in chronic toxicity studies, a LOEL of 600 $mg{\cdot}kg^{-1}$ (2250 $mg{\cdot}m^{-3}$) was observed, with histopathological changes occurring in the female rats. Fetotoxic effects due to continuous inhalation exposure of toluene at 133 to 2000 $mg{\cdot}kg^{-1}$ (7,500 $mg{\cdot}m^{-3}$) have also been observed (Donald et al. 1991).

Ethylbenzene

Acute toxicological studies of the effects of ethylbenzene on rats by Pyykkö et al. (1987) showed a fifty percent increase in cytochrome P_{450} in the liver and a sixty percent decrease in cytochrome P_{450} in the lungs. Despite the significant P_{450} changes, no alterations in liver or lung weights were noted. Ethylbenzene has also been shown to reduce brain dopamine levels in both striatal and tuberoinfundibular regions (Romanelli et al. 1986). The changes in brain dopamine levels were not found to result from any type of solvent effect on membranes but rather, resulted from metabolic interferences of ethylbenzene metabolites on the catabolism of dopamine.

Ethylbenzene is a relatively non-toxic compound with the oral LD_{50} for rats ranging from 3.5 to 4.7 $g{\cdot}kg^{-1}$ (Wolf et al. 1956; Smyth Jr. et al. 1962). Dermal application of ethylbenzene resulted in an LD_{50} of 15,400 $mg{\cdot}kg^{-1}$ (Smyth Jr. et al. 1962). The effects of ethylbenzene inhalation vary from nasal and eye irritation to vertigo, ataxia, and lung edema at concentrations from 1,000 to 10,000 ppm.

Chronic exposure of rats to ethylbenzene showed sporadic incidence of salivation and lacrimation, increase in liver weight, increases in liver to body weight ratios and liver to brain weight ratios, and increases in platelet counts (Cragg et al. 1989). The authors suggest that the liver weight and ratio changes are due to an adaptive ability of the microsomal enzymes rather than to direct toxic effects. Cragg et al. (1989) observed no effects on rabbits exposed to ethylbenzene up to 1,610 ppm at which point the animals exhibited a reduced body weight. The results of this study showed that ethylbenzene did not accumulate when chronically inhaled. The results of Elovaara et al. (1985) support the Cragg et al. (1989) view that the increase in liver and kidney cytochrome P_{450}, and the dose related increase in microsomal hepatic protein (with no indication of liver injury), provide no indication as to whether the organs are undergoing an adaptive or toxic response.

Xylenes

Acute exposure to xylenes has been reported to damage the central nervous system. Carpenter et al. (1975) reported a time dependent pattern of salivation, ataxia and spasms followed by death within two hours when rats were exposed to 9,500 ppm of mixed xylene (ethylbenzene comprised approximately 20% of the xylenes mixture). In a concurrent study with rats exposed to 11,000 ppm xylenes, toxic effects progressed from eye irritation to prostration, tremors, and death. Rats exposed to 9,900 ppm xylenes have suffered from hemorrhage and interlobular edema of the lungs (Carpenter et al. 1975). Most of the damage has been attributed to the inactivation/reduction of cytochrome P_{450} in the lungs (Stickney et al. 1989; Roberts et al. 1986, 1988; Elovaara *et al.* 1987). Condie et al. (1988) reported the lowest NOAEL (on body and liver weights) at 250 $mg{\cdot}kg^{-1}$ $bw{\cdot}d^{-1}$ in short-term studies with rats.

Xylenes have a relatively low toxicity in the rat, with acute oral LD_{50} ranging from 4,300 to 5,800 $mg{\cdot}kg^{-1}$ (Wolf et al. 1956; Ungvary 1979). LC_{50}'s ranging from 6,350 to 6,700 ppm have been reported with rat inhalation studies (Hine et al. 1970; Carpenter et al. 1975). The toxicity of xylenes mixtures will depend on the relative proportions of its constituent isomers. Gerarde (1959), in an acute oral toxicity study with rats found an LD_{70} of 4,401 $mg{\cdot}kg^{-1}$ for *o*-xylene, an LD_{30} of 4,421 $mg{\cdot}kg^{-1}$ for *m*-xylene and an LD_{60} of 4,306 $mg{\cdot}kg^{-1}$ for *p*-xylene.

With subacute/chronic studies, xylenes have been shown in rats to induce the cytochrome P_{450} in liver (Raunio et al. 1990) and kidney (Elovaara 1982), but to destroy the cytochrome P_{450} of the lungs, even at low exposure levels (Elovaara et al. 1987). Additional effects of chronic xylenes exposure include changes in body weight, liver, kidney, heart, spleen, brain and thymus weights as well as aggressiveness and alterations in white blood cells (Condie et al. 1988). In the chronic toxicity and carcinogenic studies with male rats, the NOEL and LOEL (5 to 8% decrease in body weight and survival) were observed at 250 and 500 $mg{\cdot}kg^{-1}$ $bw{\cdot}d^{-1}$ (NTP 1986).

A study on the teratogenic effects indicates that xylenes can cross the placenta in the mouse (Marks et al. 1982). Xylenes administered via gavage at 2.4 $ml{\cdot}kg{\cdot}d^{-1}$ on days 6 to 15 of gestation resulted in a greater than average number of malformed fetuses. Abnormalities included cleft palate and/or open eye, which are indicators of delayed development, and decreased average fetal weight. The study concluded that at these doses, mixed xylenes were teratogenic as well as embryotoxic to mice.

CHAPTER 6. DERIVATION OF ENVIRONMENTAL SOIL QUALITY GUIDELINES

The derivation of environmental soil quality guidelines for toluene, ethylbenzene, and xylenes is outlined in the following sections for four land uses: agricultural, residential/parkland, commercial, and industrial. Various modifications to the CCME (1996) protocol that were used in the Canada-wide Standard for Petroleum Hydrocarbons in Soil (CCME 2000) were also applied in the development of these guidelines. Modifications include the derivation of guidelines for different soil textures (coarse and fine) and depths (surface soil and subsoil). As defined in the Canada-wide Standard for Petroleum Hydrocarbons, fine-grained soils are those which contain greater than 50% by mass particles less than 75 µm mean diameter ($D_{50}<75$ µm). Coarse-grained soils are those that contain greater than 50% by mass particles greater than 75 µm mean diameter ($D_{50}>75$ µm). Surface soil refers to the unconsolidated mineral material on the immediate surface of the earth that serves as a natural medium for terrestrial plant growth, and can extend as deep as 1.5 m. Subsoil is defined as the unconsolidated regolith material above the water table not subject to soil forming processes; this nominally includes vadose zone materials below 1.5 m depth. According to the protocol, these environmental soil quality guidelines for toluene, ethylbenzene and xylenes will be considered along with the human health guidelines in making final recommendations for Canadian Soil Quality Guidelines for the protection of environmental and human health (CCME 1996; see Chapter 8).

The environmental soil quality guidelines for TEX are derived using the available toxicological data to determine the threshold level of effects for key ecological receptors. Exposure from direct soil contact is the primary derivation procedure used for calculating environmental quality guidelines for residential/parkland, commercial, and industrial land uses. Exposure from direct soil contact as well as soil and food ingestion is considered in calculating guidelines for agricultural land use, with the lower of the two values generated from these derivation procedures being recommended as the environmental soil quality guideline for this land use. In addition to these primary derivation procedures, check mechanisms are used to consider important direct and indirect soil exposure pathways, such as protection of groundwater for aquatic life and for livestock.

All data selected for use in the following derivations have been screened for ecological relevance and are presented in Appendices XII (toluene), XIII (ethylbenzene) and XIV (xylenes). Studies that have been consulted but not used in guideline derivation are presented in Appendices VI - XI. Studies were excluded from use because of one or more of the following reasons:

- soil pH was not recorded;
- soil pH was below 4 (as this is considered outside the normal pH range of most soils in Canada)
- no indication of soil texture was provided;
- inappropriate statistical analysis was used;

- test was not conducted using soil or artificial soil;
- test soil was amended with sewage sludge or a mixture of toxicants; and/or,
- test did not use controls.

Generally, very little information on the toxicity of TEX to soil organisms (microbes, invertebrates and plants) in direct soil contact was found.

Attempts to generate toxicological data by Environment Canada (1995) for use in the derivation of soil quality criteria have demonstrated the problems associated with testing volatile organic compounds. Two tests were run for each VOC, yet sampling and handling problems persisted. Generally the amount of VOC applied and the amount actually measured in the soil differed by an order of magnitude, which was considered unacceptable. Due to these problems, the data from Environment Canada (1995) were not used in deriving the environmental soil quality guidelines.

There were sufficient acceptable data available to meet the minimum data requirements described in the Protocol (CCME 1996) for the derivation of soil quality guidelines based on soil contact (SQG_{SC}). The available dataset was not sufficient to meet the minimum requirements of the protocol for calculating the soil and food ingestion (SQG_I); however, the process used to determine tolerable daily intakes for humans was adapted to calculate daily threshold doses for livestock. There were insufficient data available to calculate a nutrient and energy cycling check for any of the categories of land use. Additional research on the toxicity, bioaccumulation, and biomagnification in terrestrial organisms is required.

Agricultural and Residential/Parkland Land Uses

Soil Contact

The derivation of the soil quality guideline for soil contact (SQG_{SC}) is based on toxicological data for vascular plants and soil invertebrates. The toxicological data for plants and invertebrates selected according to CCME (1996) are presented in Appendices XII - XIV.

ESG (2001, 2002a) conducted 14-day studies with both coarse and fine soils for two plant species, *Agropyron dasystachyum* (early northern wheatgrass) and *Medicago sativa* (alfalfa), and two invertebrate species, *Eisenia andrei* (earthworm) and *Onychiurus folsomi* (collembolan). Procedures were adopted to minimize the loss of volatile compounds from the test vessels. To determine the actual concentrations of TEX to which the organisms were exposed, chemical analyses were conducted immediately after the soils were spiked. However, organisms were not introduced to the soils until 2 hours later (plants) or 24 hours later (invertebrates). Therefore, further work was done to determine the amount of TEX that would have been lost from the soil between spiking and introduction of the organisms (ESG 2002b). Due to budget limitations, this work was conducted using the coarse artificial soil only. The information on TEX losses from coarse soils was used to adjust the estimates of the initial concentrations to which the organisms were exposed. The LC_{25}, IC_{25} and LOEC values based on nominal concentrations of TEX were converted to "estimated effect" LC_{25}, IC_{25} and LOEC values using regression equations based on the analysis of samples collected 2 hours (for plants) or 24 hours (for invertebrates) after spiking. For the fine field-collected soil, the regression equations were based on the analysis of samples collected immediately after soil spiking.

A modification was made to the ESG dataset prior to calculating the guidelines (Komex 2002). The "estimated effect" LC_{25}, IC_{25}, and LOEC concentrations for the fine soil were recalculated using the 2 and 24 hour regression equations (for plants and invertebrates, respectively) for coarse soil, rather than the "time zero" regression equations for fine soil. It is expected that volatile losses in the period following spiking will be more rapid for the coarse soil than for the fine soil, and accordingly it was considered conservative to apply the 2 and 24 hour coarse soil regression equations to the fine soils.

There were sufficient toxicological data to use the preferred weight of evidence (WOE) method for guideline derivation. ESG (2002b) found that it was not possible to calculate meaningful LC_{25} values for the *Eisenia andrei* tests, based on the "all or nothing" nature of the data (i.e., little mortality was seen at the NOEC, and almost complete mortality was observed at the LOEC). Therefore, the EC_{25} Distribution WOE method could not be used. Instead, the Effects/No Effects Data Distribution WOE method was used, incorporating IC_{25} values for the northern wheatgrass and alfalfa, LC_{25} values for the collembolan, and LOEC values for the earthworm. The derivation of the SQG_{SC} followed a procedure modified from the Canada-wide Standard for Petroleum Hydrocarbons (CCME 2000). The procedure was as follows:

- For each distinct test/endpoint, only the data representing a 25% effect (e.g., LC_{25} or EC_{25}) were considered, with the exception of the earthworm tests for which the LOECs were considered;
- If tests differed only in duration, only the data for the longest duration were used;
- If multiple data were available for the same chemical, endpoint and species, these data were replaced by their geometric mean;
- For agricultural and residential/parkland land uses, the SQG_{SC} was calculated as the 25th percentile of plant and invertebrate data.

For the plant data, measurements of shoot dry weight and shoot wet weight for the same species were considered as multiple data and were therefore replaced by their geometric mean. Similarly, a geometric mean was used to replace measurements of root dry weight and root wet weight for the same plant species.

Toluene

Rank percentiles of the toxicity data distribution for toluene were plotted against the LC_{25} concentrations for coarse (Figure 1) and fine (Figure 2) soil.

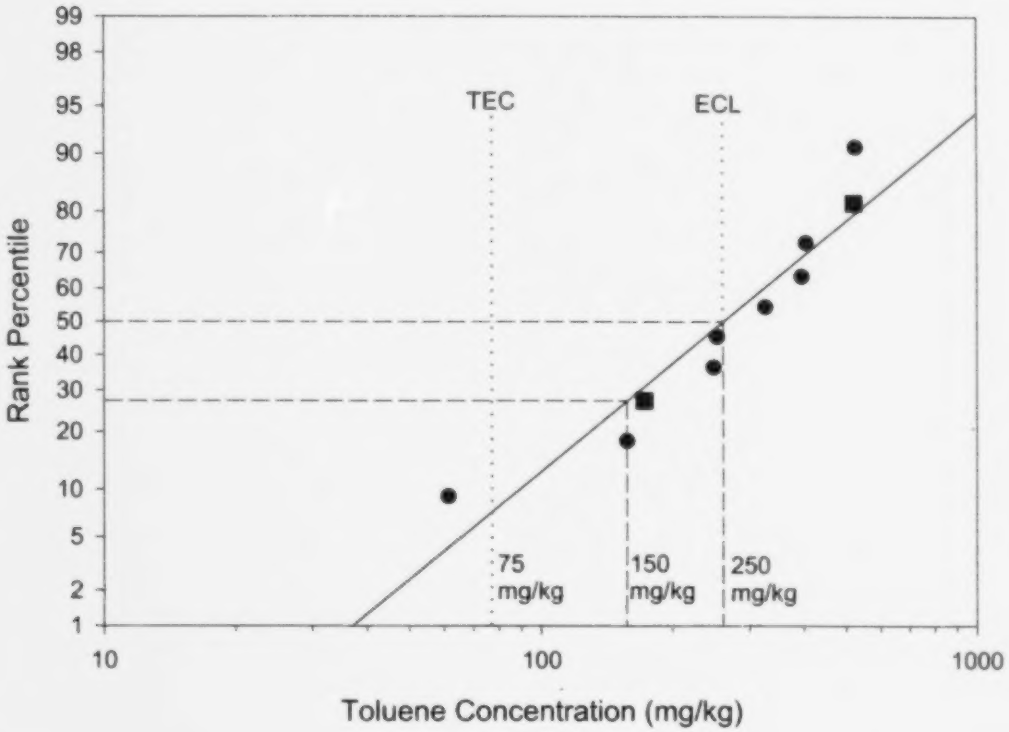

Figure 1. Rank percentile plot of toxicity data distribution for plants (●) and invertebrates (■) exposed to toluene in coarse soil.
TEC = threshold effects concentration
ECL = effects concentration low

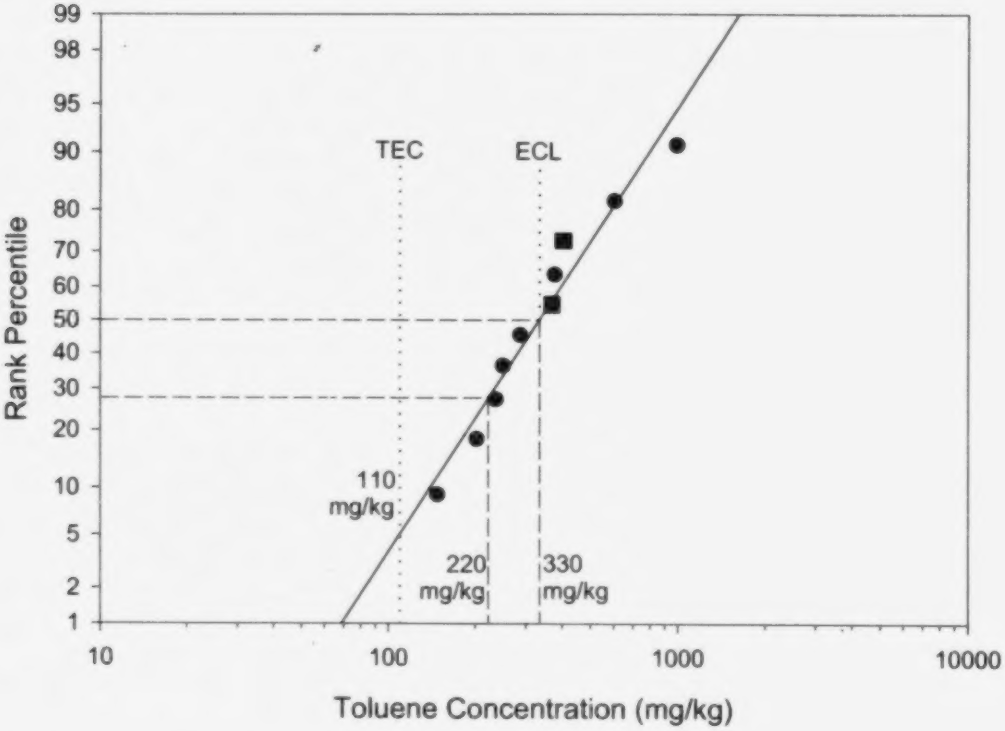

Figure 2. Rank percentile plot of toxicity data distribution for plants (●) and invertebrates (■) exposed to toluene in fine soil.
TEC = threshold effects concentration
ECL = effects concentration low

The 25th percentile of the rank distribution, as estimated from the graph, was chosen to represent the no potential effects range (NPER) for the agricultural and residential/parkland land uses. The TEC was calculated using the following equation:

$$TEC = NPER / UF$$

where,

TEC = threshold effects concentration ($mg\cdot kg^{-1}$)
NPER = no potential effects range (25th percentile of the distribution) ($mg\cdot kg^{-1}$)
UF = uncertainty factor (if needed).

An uncertainty factor of 2 was deemed necessary due to the limited number of species represented in the data distribution.

Using the above procedure, the surface soil SQG_{SC} value for toluene in both agricultural and residential/parkland land uses was calculated as 75 $mg\cdot kg^{-1}$ for coarse soils and

110 mg·kg^{-1} for fine soils.

Subsoil guidelines for soil contact were calculated based on management decisions made in the PHC CWS (CCME 2000). In the PHC CWS, subsoil guidelines were between 2 and 6 times greater than surface soil guidelines, based on the lower biological activity levels at subsoil depths, but also taking into account other considerations such as aesthetics, safety, and underground infrastructure. For toluene, subsoil SQG_{SC} values for this pathway were calculated as twice the corresponding surface soil guideline (with consideration that surface soil values have been previously rounded), i.e., 150 mg·kg^{-1} for coarse soils and 220 mg·kg^{-1} for fine soils.

Ethylbenzene

Rank percentiles of the toxicity data distribution for ethylbenzene were plotted against the LC_{25} concentrations for coarse (Figure 3) and fine (Figure 4) soil.

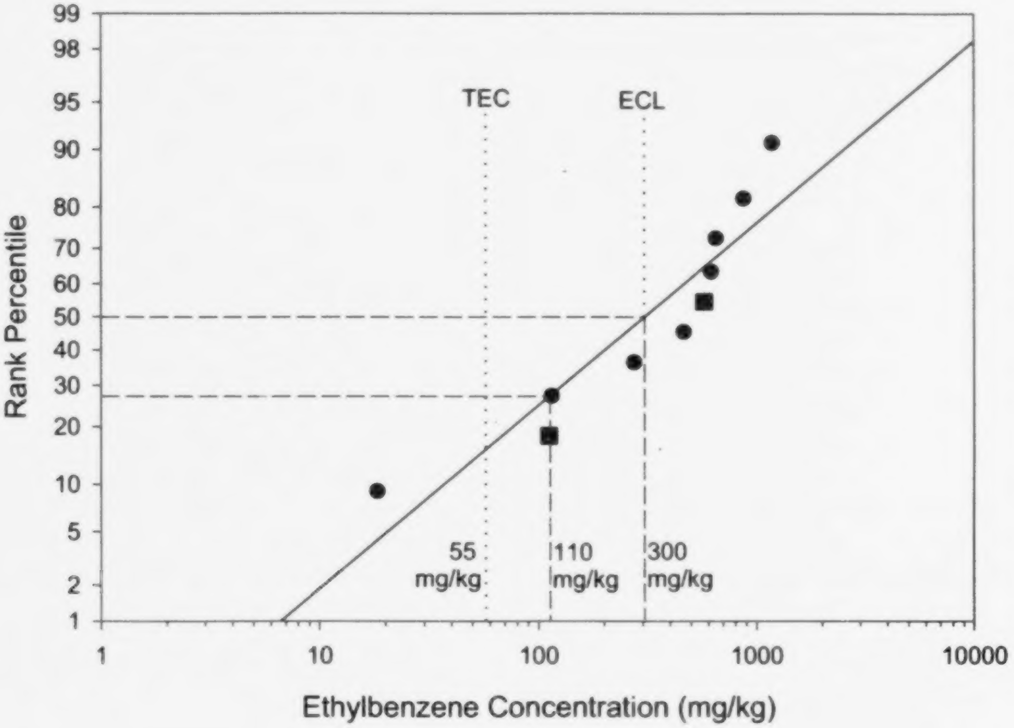

Figure 3. Rank percentile plot of toxicity data distribution for plants (•) and invertebrates (■) exposed to ethylbenzene in coarse soil.
TEC = threshold effects concentration
ECL = effects concentration low

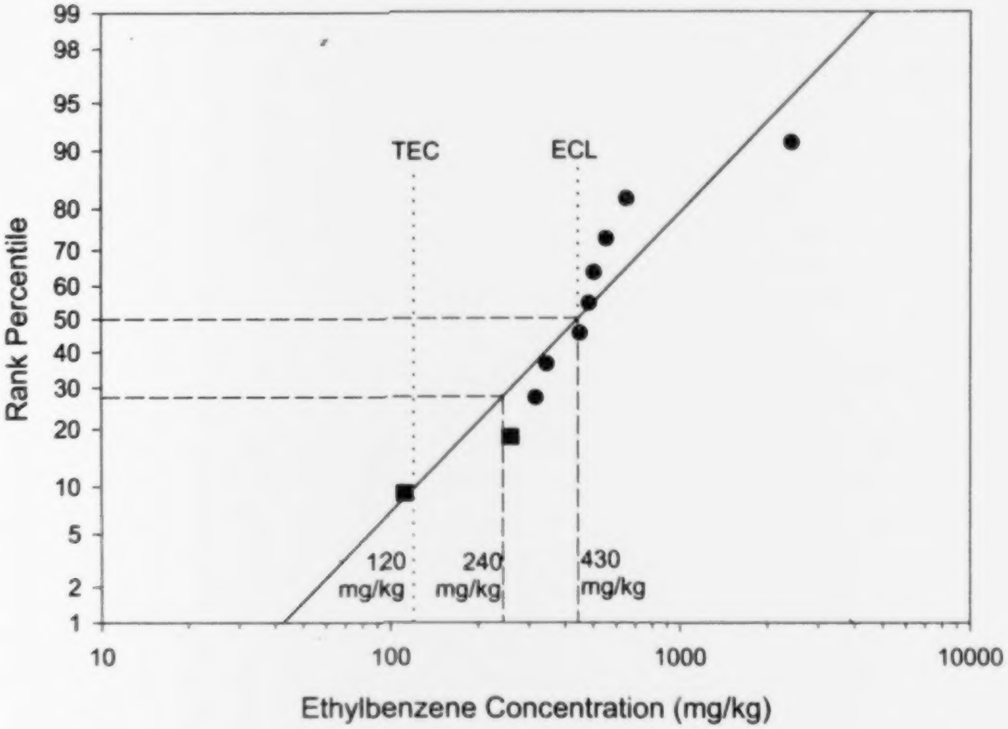

Figure 4. Rank percentile plot of toxicity data distribution for plants (●) and invertebrates (■) exposed to ethylbenzene in fine soil.
TEC = threshold effects concentration
ECL = effects concentration low

The 25th percentile of the rank distribution, as estimated from the graph, was chosen to represent the no potential effects range (NPER) for the agricultural and residential/parkland land uses. The TEC was calculated using the following equation:

$$\text{TEC} = \text{NPER} / \text{UF}$$

where,

TEC = threshold effects concentration ($mg \cdot kg^{-1}$)
NPER = no potential effects range (25th percentile of the distribution) ($mg \cdot kg^{-1}$)
UF = uncertainty factor (if needed).

An uncertainty factor of 2 was deemed necessary due to the limited number of species represented in the data distribution.

Using the above procedure, the surface soil SQG_{SC} value for ethylbenzene in both agricultural and residential/parkland land uses was calculated as 55 $mg \cdot kg^{-1}$ for coarse soils and 120 mg·kg^{-1} for fine soils.

Subsoil guidelines for soil contact were calculated based on management decisions made in the PHC CWS (CCME 2000). In the PHC CWS, subsoil guidelines were between 2 and 6 times greater than surface soil guidelines, based on the lower biological activity levels at subsoil depths, but also taking into account other considerations such as aesthetics, safety, and underground infrastructure. For ethylbenzene, subsoil SQG_{SC} values for this pathway were calculated as twice the corresponding surface soil guideline (with consideration that surface soil values have been previously rounded), i.e., 110 mg·kg^{-1} for coarse soils and 240 mg·kg^{-1} for fine soils.

Xylenes

Rank percentiles of the toxicity data distribution for xylenes were plotted against the LC_{25} concentrations for coarse (Figure 5) and fine (Figure 6) soil.

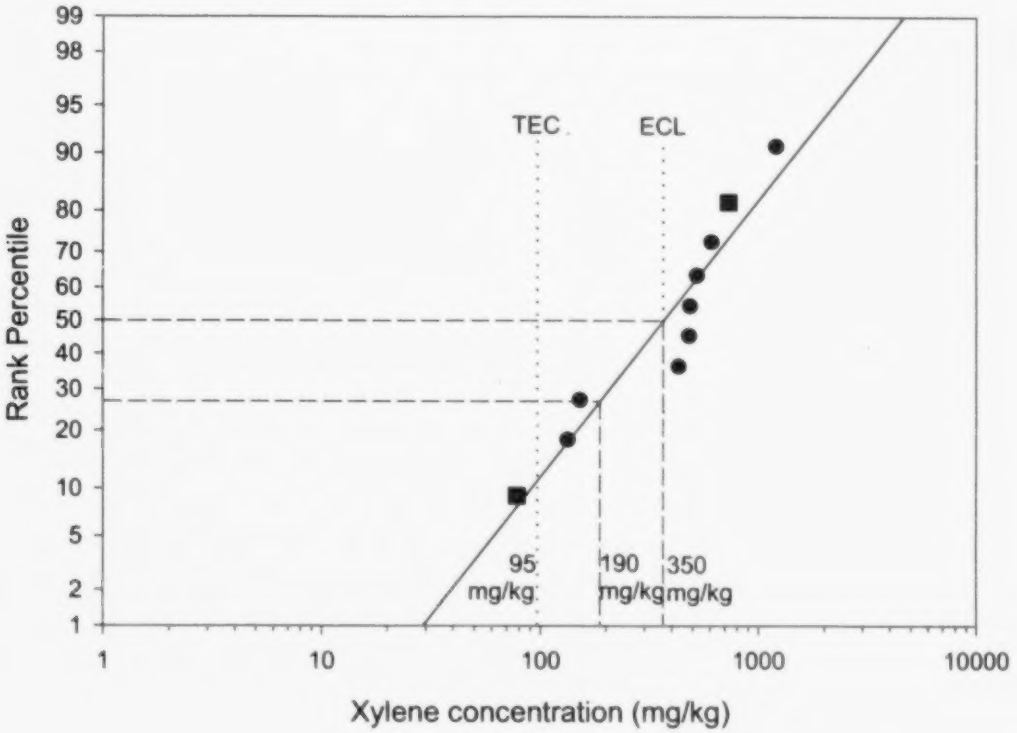

Figure 5. Rank percentile plot of toxicity data distribution for plants (•) and invertebrates (■) exposed to xylenes in coarse soil.
TEC = threshold effects concentration
ECL = effects concentration low

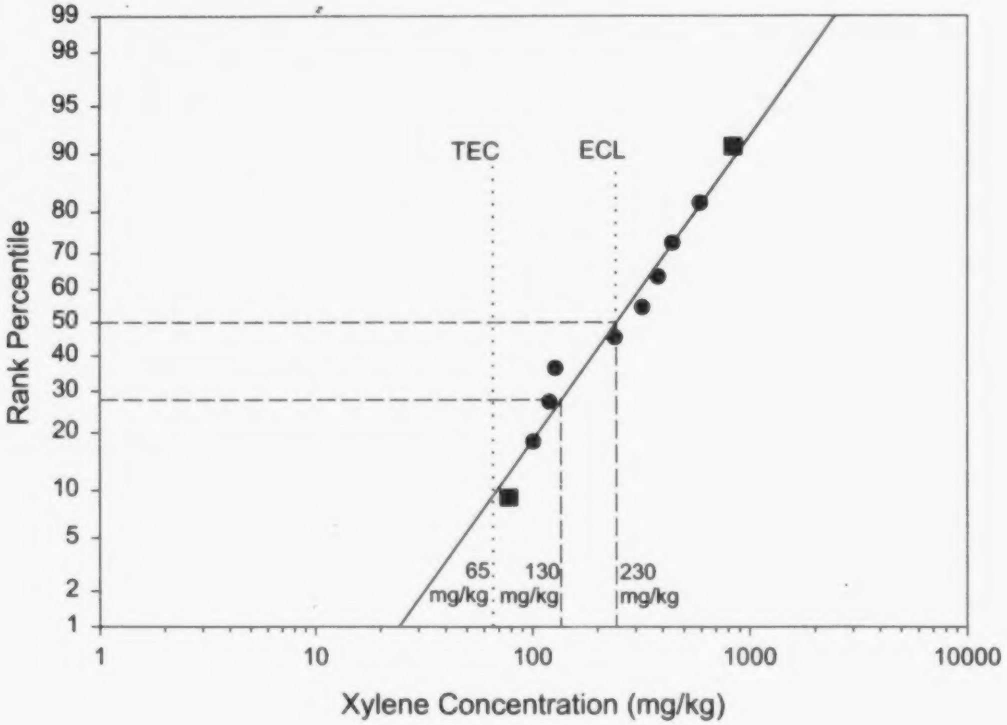

Figure 6. Rank percentile plot of toxicity data distribution for plants (●) and invertebrates (■) exposed to xylenes in fine soil.
TEC = threshold effects concentration
ECL = effects concentration low

The 25th percentile of the rank distribution, as estimated from the graph, was chosen to represent the no potential effects range (NPER) for the agricultural and residential/parkland land uses. The TEC was calculated using the following equation:

$$TEC = NPER / UF$$

where,

TEC = threshold effects concentration ($mg \cdot kg^{-1}$)
NPER = no potential effects range (25th percentile of the distribution) ($mg \cdot kg^{-1}$)
UF = uncertainty factor (if needed).

An uncertainty factor of 2 was deemed necessary due to the limited number of species represented in the data distribution.

Using the above procedure, the surface soil SQG_{SC} value for xylenes in both agricultural and residential/parkland land uses was calculated as 95 $mg \cdot kg^{-1}$ for coarse soils and 65 $mg \cdot kg^{-1}$ for fine soils.

Subsoil guidelines for soil contact were calculated based on management decisions made in the PHC CWS (CCME 2000). In the PHC CWS, subsoil guidelines were between 2 and 6 times greater than surface soil guidelines, based on the lower biological activity levels at subsoil depths, but also taking into account other considerations such as aesthetics, safety, and underground infrastructure. For xylenes, subsoil SQG_{SC} values for this pathway were calculated as twice the corresponding surface soil guideline (with consideration that surface soil values have been previously rounded), i.e., 190 $mg \cdot kg^{-1}$ for coarse soils and 130 $mg \cdot kg^{-1}$ for fine soils.

Nutrient and Energy Cycling Check

A nutrient and energy cycling check could not be calculated due to insufficient data.

Soil and Food Ingestion

The soil quality guideline for ingestion (SQG_I) applies only to agricultural land use.

To calculate a guideline for this pathway, the CCME (1996) protocol requires the determination of a daily threshold effect dose (DTED) for livestock and grazing wildlife. A DTED is defined as a dose level below which adverse effects are not expected in a receptor. The minimum data requirements in the CCME (1996) protocol for calculating a DTED include at least one study on a grazing herbivore and one oral avian study. These data requirements were not met for TEX. The Soil Quality Guidelines Task Group of CCME felt that management of TEX would be better served by having guidelines for this exposure pathway than by having no guidelines, so an alternative protocol for estimating the DTEDs was adopted as follows.

Toluene

Health Canada and Environment Canada (1992) reviewed the mammalian toxicology of toluene and concluded that the best documented and most complete oral mammalian study conducted to date was an NTP bioassay in rats and mice (Huff 1990). In that study, rats were orally gavaged with doses ranging from 0 to 5,000 $mg \cdot kg^{-1}$ in corn oil for 13 weeks (5 days/week). The reported LOAEL, based on organ weight and histopathologic changes in the liver and kidney, was 625 $mg \cdot kg^{-1}\ bw \cdot d^{-1}$. When adjusted for a continuous exposure (i.e., to 7 days/week from 5 days/week), the LOAEL becomes 446 $mg \cdot kg^{-1}\ bw \cdot d^{-1}$. A 100-fold uncertainty factor was applied, based on a 10-fold factor to account for the use of a LOAEL from a less than chronic duration study, and a further 10-fold factor to account for the uncertainties in extrapolating from one species to another, to give a DTED of 4.46 $mg \cdot kg^{-1}\ bw \cdot d^{-1}$.

$$DTED\ (toluene) = \frac{625 \times (5/7)}{100} = 4.46\ mg \cdot kg^{-1}\ bw \cdot d^{-1}$$

Ethylbenzene

Health Canada has not reviewed the oral mammalian toxicology of ethylbenzene. The USEPA (1991), however, have reviewed the literature, and selected Wolf et al. (1956) as the principal study on which to base their human reference dose. In this study, rats were orally gavaged with doses ranging from 14 to 680 mg/kg in olive oil for 182 days (5 days/week). The reported LOAEL, based on histopathologic changes in the liver and kidney, was 408 $mg \cdot kg^{-1}$ $bw \cdot d^{-1}$. When adjusted for a continuous exposure (i.e., to 7 days/week from 5 days/week), the LOAEL becomes 291 $mg \cdot kg^{-1}$ $bw \cdot d^{-1}$. The oral DTED for ethylbenzene was derived based on the above-noted LOAEL and a 100-fold uncertainty factor.

$$DTED\ (ethylbenzene) = \frac{408 \times (5/7)}{100} = 2.91\ mg \cdot kg^{-1}\ bw \cdot d^{-1}$$

Xylenes

Health Canada and Environment Canada (1993) reviewed the mammalian toxicology of xylenes and concluded that the best documented and most complete oral mammalian study conducted to date was an NTP bioassay in rats and mice (NTP 1986). In that study, rats were orally gavaged with doses ranging from 0 to 1 000 $mg \cdot kg^{-1}$ for 103 weeks (5 days/week). The reported LOAEL, based on central nervous system toxicity, was 500 $mg \cdot kg^{-1}$ $bw \cdot d^{-1}$. When adjusted for a continuous exposure (i.e., to 7 days/week from 5 days/week), the LOAEL becomes 357 $mg \cdot kg^{-1}$ $bw \cdot d^{-1}$. A 30-fold uncertainty factor was applied, based on a 3-fold uncertainty factor to account for uncertainties within the toxicological database, and a further 10-fold factor to account for the uncertainties in extrapolating from one species to another. Note that the overall uncertainty factor of 30 differs from the overall uncertainty factors of 100 used for benzene, toluene, and ethylbenzene. This follows the approach taken by Health Canada and Environment Canada (1993) for deriving a TDI for humans. The NTP (1986) study is of chronic duration, so a 10-fold safety factor to account for "less than chronic duration" is not required. However, other uncertainties in the toxicological database call for a 3-fold safety factor.

$$DTED\ (xylenes) = \frac{500 \times (5/7)}{30} = 11.9\ mg \cdot kg^{-1}\ bw \cdot d^{-1}$$

An animal may be exposed to a contaminant by more than one route. Total exposure comes from a combination of contaminated food, direct soil ingestion, dermal contact, contaminated drinking water, and inhalation of air and dust. Exposure from all of these routes should not exceed the DTED. Assuming that drinking water, dermal contact and inhalation account for 25% of the total exposure (CCME 1996), the remaining 75% of exposure is attributed to the ingestion of food and soil. It follows then that exposure from soil and food ingestion should not exceed 75% of the DTED.

The soil ingestion rate was calculated as:

$$SIR = \frac{FIR \times PSI}{1 - PSI} = 1.674\ kg \cdot d^{-1}$$

where,

SIR = soil ingestion rate for dairy cattle (Appendix XV);
FIR = food ingestion rate for dairy cattle (Appendix XV); and,
PSI = proportion of soil ingested by dairy cattle (Appendix XV).

Bioconcentration of TEX into livestock fodder is not expected to be significant, thus a guideline was calculated only for the livestock soil ingestion (and not food ingestion) pathway. The SQG_I was calculated, based on exposure to a dairy cow, using the following equation:

$$SQG_I = \frac{0.75 \times DTED \times BW}{SIR \times BF}$$

where,

SQG_I = soil ingestion guideline; concentration of the contaminant in soil that will not result in animals being exposed to greater than 75% of the DTED ($mg \cdot kg^{-1}$ soil);
DTED = daily threshold effect dose for livestock (obtained above);
BW = body weight for dairy cattle (Appendix XV);
SIR = soil ingestion rate for dairy cattle; and,
BF = bioavailability factor (1; assumed).

Substituting these values into the above equation and rounding to 2 significant figures yields an SQG_I value for agricultural land use (surface soil) of 1400 $mg \cdot kg^{-1}$ for toluene, 910 $mg \cdot kg^{-1}$ for ethylbenzene and 3 700 $mg \cdot kg^{-1}$ for xylenes (Tables 2, 4 and 6).

Commercial and Industrial Land Uses

Soil Contact

As for agricultural and residential/parkland land uses, the derivation of the SQG_{SC} for commercial and industrial land uses followed a procedure modified from the Canada-wide Standard for Petroleum Hydrocarbons (CCME 2000) (see description above). For commercial and industrial land uses, however, the SQG_{SC} was calculated as the 50th percentile of the plant and invertebrate data, also referred to as the effects concentration low (ECL). Using this procedure, the surface soil SQG_{SC} value for toluene for both commercial and industrial land uses was calculated as 250 $mg \cdot kg^{-1}$ for coarse soils, and 330 $mg \cdot kg^{-1}$ for fine soils (see Figures 1 and 2). For ethylbenzene, the surface soil SQG_{SC} value for both commercial and industrial land uses was calculated as 300 mg·kg^{-1} for coarse soils, and 430 mg·kg^{-1} for fine soils (see Figures 3 and 4). For xylenes, the surface soil SQG$_{SC}$ value for both commercial and industrial land uses was calculated as 350 mg·kg^{-1} for coarse soils, and 230 mg·kg^{-1} for fine soils (see Figures 5 and 6).

Subsoil guidelines for soil contact were calculated based on management decisions made in the PHC CWS (CCME 2000). In the PHC CWS, subsoil guidelines were between 2 and 6 times greater than surface soil guidelines, based on the lower biological activity levels at subsoil depths, but also taking into account other considerations such as aesthetics, safety, and underground infrastructure. For TEX, subsoil SQG$_{SC}$ values for both commercial and industrial land uses were calculated as twice the corresponding surface soil guideline. Using these procedures, the surface soil and subsoil SQG$_{SC}$ value for both commercial and industrial land uses were calculated and final values are presented in Tables 2 to 7.

Nutrient and Energy Cycling Check

A nutrient and energy cycling check could not be calculated due to insufficient data.

Final Environmental Soil Quality Guidelines

The final environmental soil quality guidelines (SQG$_E$) for TEX for the two soil textures and two soil depths in each of the four land uses are presented as a summary in Table 1 and are detailed in Tables 2 to 7. The lower value from the two pathways (SQG$_{SC}$ and SQG$_I$) is selected as the final SQG$_E$ for surface soils on all land uses. Because no SQG$_I$ was calculated for subsoils, the final SQG$_E$ for subsoils are the calculated SQG$_{SC}$.

Table 1. Summary of the final environmental soil quality guidelines (SQG$_E$) for TEX (mg·kg^{-1}).

		Agricultural		**Residential/ parkland**		**Commercial**		**Industrial**	
		Coarse	**Fine**	**Coarse**	**Fine**	**Coarse**	**Fine**	**Coarse**	**Fine**
Toluene	surface soil	75	110	75	110	250	330	250	330
	subsoil	150	220	150	220	500	660	500	660
Ethylbenzene	surface soil	55	120	55	120	300	430	300	430
	subsoil	110	240	110	240	600	860	600	860
Xylenes	surface soil	95	65	95	65	350	230	350	230
	subsoil	190	130	190	130	700	460	700	460

Groundwater Checks

Soils are hydrologically linked to groundwater systems. A major concern with soil contamination is that it can and does lead to groundwater contamination. Two checks (one for the protection of aquatic life, and one for the protection of livestock watering) were calculated to determine maximum soil concentrations of TEX that will not result in unacceptable transfers of contaminants to groundwater. These check values were not used in determining the national soil quality guidelines, but are provided as a reference for site-specific application in areas underlying groundwater systems.

Protection of Groundwater for Aquatic Life

Prudent assumptions are that an aquifer underlying a remediated site may have the potential to enter surface water bodies. Therefore, the following equations are used to calculate the concentration in soil that will not cause an excess of groundwater concentrations above existing water quality guidelines for the protection of freshwater aquatic life. The groundwater check follows the rationale and calculation procedure from the PHC CWS (CCME 2000). Aquatic life groundwater check values are the same for all land uses and for both surface soil and subsoil. The check value for this pathway is based on the concentration of dissolved toluene, ethylbenzene or xylenes at a distance of 10 metres from the source, and at a time of 100 years after the compound was introduced to the soil. A check value has not been calculated for fine soils because a groundwater migration calculation using parameters for fine soil shows that in 100 years, groundwater does not flow 10 metres. It should be noted, however, that if making Tier 2 calculations at a site where the protection of this groundwater pathway is active, a hydraulic conductivity of 32 metres per year should be assumed, if adequate measured data are not available.

For toluene and ethylbenzene, the calculation of the groundwater check is based on the existing Canadian water quality guidelines for the protection of aquatic life (CCME 1999). However, as a Canadian water quality guideline for the protection of aquatic life does not currently exist for xylenes, an aquatic life threshold value was estimated using the available aquatic toxicity data for xylenes, as described in Komex (2002). The groundwater checks were then calculated using the guideline (or the threshold value in the case of xylenes) and a dilution factor calculated for each of four processes:

1. partitioning from soil to leachate;
2. transport of leachate from base of contamination to water table;
3. mixing of leachate and groundwater; and,
4. groundwater transport downgradient to surface water receptor.

Calculations of dilution factors for each of these four processes are shown below.

Dilution Factor 1

Dilution factor 1 is the ratio of the concentration of a contaminant in soil to the concentration in leachate that is in contact with the soil. This dilution factor represents the three phase partitioning between contaminant sorbed to soil, contaminant dissolved in pore water (i.e., as leachate), and contaminant present as soil vapour. It is calculated using the following equation:

$$DF1 = K_{oc} f_{oc} + \frac{(\theta_w + H'\theta_a)}{\rho_b}$$

where,

DF1 = dilution factor 1 ($L \cdot kg^{-1}$);
K_{oc} = organic carbon partition coefficient (Appendix XVII);
f_{oc} = fraction organic carbon (Appendix XV);
θ_w = moisture-filled porosity (Appendix XVI);
H' = dimensionless Henry's Law constant (Appendix XVII);
θ_a = vapour-filled porosity (Appendix XVI); and,
ρ_b = dry soil bulk density (Appendix XVI).

Substituting these values in the above equation yields a DF1 value of 1.29 for toluene, 2.81 for ethylbenzene and 3.04 for xylenes.

Dilution Factor 2

Dilution factor 2 is the ratio of the concentration of a contaminant in leachate that is in contact with the soil, to the concentration in pore water just above the groundwater table. DF2 takes the value 1.00 (i.e., no dilution) for generic guidelines because it is assumed at Tier 1 that the contaminated soil extends down to the water table.

Dilution Factor 3

Dilution factor 3 is the ratio of the concentration of a chemical in pore water just above the groundwater table, to the concentration in groundwater beneath the source. This dilution factor reflects a decrease in concentration as leachate mixes with uncontaminated groundwater. DF3 is a function of groundwater velocity, infiltration rate, source length, and mixing zone thickness. The mixing zone thickness is calculated as being due to two processes, mixing due to dispersion, and mixing due to infiltration rate.

The equations used are as follows:

$$DF3 = 1 + \frac{Z_d V}{IX}$$

$$Z_d = r + s$$

$$r = 0.01X$$

$$s = d_a\left\{1 - \exp\left(\frac{-2.178XI}{Vd_a}\right)\right\}$$

$$V = Ki$$

where,

DF3 = dilution factor 3 (dimensionless);
Z_d = average thickness of mixing zone (calculated above);
V = Darcy velocity in groundwater (calculated above);
I = infiltration (recharge) rate (Appendix XVI);
X = length of contaminated soil (Appendix XV);
r = mixing depth due to dispersion (calculated above);
s = mixing depth due to infiltration rate (calculated above);
d_a = unconfined aquifer thickness (Appendix XV);
K = aquifer hydraulic conductivity (Appendix XVI); and,
i = lateral hydraulic gradient in aquifer (Appendix XV).

Substituting these values in the above equations yields a DF3 for TEX of 3.67 for coarse soil.

Dilution Factor 4

Dilution factor 4 accounts for the processes of dispersion and biodegradation as groundwater travels downgradient from beneath the source of contamination, and is the ratio of the concentration of a chemical in groundwater beneath the source, to the concentration in groundwater at a distance (10 m for Tier 1) downgradient of the source. DF4 was calculated using the following equations:

$$DF4 = \frac{4}{\exp(A)\times erfc(B)\times\left[erf(C) - (D)\right]}$$

$$A = \frac{x}{2D_x}\left\{1 - \left(1 + \frac{4L_s D_x}{v}\right)^{1/2}\right\}$$

$$B = \frac{x - vt\left(1 + \frac{4L_s D_x}{v}\right)^{1/2}}{2\left(D_x vt\right)^{1/2}}$$

$$C = \frac{y + \frac{Y}{2}}{2\left(D_y x\right)^{1/2}}$$

$$D = \frac{y - \frac{Y}{2}}{2\left(D_y x\right)^{1/2}}$$

$$L_s = \frac{0.691}{t_{1/2s}} \times \exp\left(-0.07d\right)$$

$$v = \frac{V}{\theta_t R_s}$$

$$R_s = 1 + \frac{\rho_b K_{oc} f_{oc}}{\theta_t}$$

$$D_x = 0.1x$$

$$D_y = 0.01x$$

where,

DF4 = dilution factor 4 (dimensionless);
erf = the error function;
erfc = the complimentary error function;
A = dimensionless group A (calculated above);
B = dimensionless group B (calculated above);
C = dimensionless group C (calculated above);
D = dimensionless group D (calculated above);
x = distance to receptor (Appendix XV);
D_x = dispersivity in the direction of groundwater flow (calculated above);
L_s = decay constant (calculated above);
v = velocity of the contaminant (calculated above);
t = time since the contaminant release (Appendix XV);
y = distance to receptor perpendicular to groundwater flow (Appendix XV);
Y = source width (Appendix XV);
D_y = dispersivity perpendicular to the direction of groundwater flow (calculated above);
$t_{1/2s}$ = decay half-life of chemical in saturated zone (Appendix XVII);
d = depth to groundwater (Appendix XV);
V = Darcy velocity in groundwater (calculated above);
θ_t = total soil porosity (Appendix XVI);
R_s = retardation factor in saturated zone (calculated above);
ρ_b = dry soil bulk density (Appendix XVI);
K_{oc} = organic carbon partition coefficient (Appendix XVII); and,
f_{oc} = fraction organic carbon (Appendix XV).

Substituting these values into the above equations yields DF4 values of 10.52 for toluene, 53.53 for ethylbenzene and 18.36 for xylenes in coarse soil.

Check value

The groundwater check for the protection of aquatic life was calculated using the following equations:

$$GWC_{AL} = WQG_{AL} \times DF$$

$$DF = DF1 \times DF2 \times DF3 \times DF4$$

where,

GWC_{AL} = groundwater check protective of aquatic life ($mg \cdot kg^{-1}$);
WQG_{AL} = water quality guideline for aquatic life (Appendix XVII);
DF = overall dilution factor;
DF1 = dilution factor 1;
DF2 = dilution factor 2;
DF3 = dilution factor 3; and,
DF4 = dilution factor 4.

Substituting these values in the above equations and rounding to 2 significant figures yields a groundwater check for the protection of aquatic life of 0.1 $mg \cdot kg^{-1}$ for toluene, 50 $mg \cdot kg^{-1}$ for ethylbenzene and 37 $mg \cdot kg^{-1}$ for xylenes in coarse soil.

Protection of Groundwater for Livestock Watering

This check value was calculated to determine the concentration of TEX in soil that will not cause groundwater concentrations to exceed acceptable levels for consumption by livestock. This pathway applies only to agricultural land uses. As with the aquatic life groundwater check, the livestock watering groundwater check is the same for both surface soils and subsoils, and is calculated only for coarse soils. The calculations for the groundwater check for the protection of livestock watering are identical to those shown above for the groundwater check for aquatic life, except that a livestock watering threshold limit is used (TL_{LW}), rather than the WQG_{AL}. This check value is provisional because at the time of derivation there was no Canadian Water Quality Guideline for the protection of livestock watering on which to base it (CCME 1999). Instead, using parameters for dairy cows, a health-based livestock watering threshold limit was calculated using the following equation:

$$TL_{LW} = \left(\frac{BW \times DTED}{IR_W \times BIO_O} \right)$$

where,

TL_{LW} = water quality threshold limit for livestock watering ($mg \cdot L^{-1}$);
BW = body weight for cattle (Appendix XV);
DTED = daily threshold effect dose for toluene, ethylbenzene or xylenes;
IR_W = drinking water ingestion rate for cattle (Appendix XV); and,
BIO_O = oral bioavailability (gut absorption factor) (1.0; assumed).

Substituting these values into the above equation and rounding to 2 significant figures yields a livestock watering threshold limit of 36 $mg \cdot L^{-1}$ for toluene, 23 $mg \cdot L^{-1}$ for ethylbenzene and 95 $mg \cdot L^{-1}$ for xylenes.

Check value

The groundwater check for the protection of livestock watering was calculated using the following equations:

$$GWC_{LW} = TL_{LW} \times DF$$

$$DF = DF1 \times DF2 \times DF3 \times DF4$$

where,

GWC_{LW} = groundwater check protective of livestock watering ($mg \cdot kg^{-1}$);
TL_{LW} = threshold limit for livestock watering;
DF = overall dilution factor;
DF1 = dilution factor 1;
DF2 = dilution factor 2;
DF3 = dilution factor 3; and,
DF4 = dilution factor 4.

Substituting these values into the above equations and rounding to 2 significant figures yields a groundwater check for the protection of livestock watering in coarse soil of 1800 $mg \cdot kg^{-1}$ for toluene, 13 000 $mg \cdot kg^{-1}$ for ethylbenzene and 20 000 $mg \cdot kg^{-1}$ for xylenes.

CHAPTER 7. DERIVATION OF HUMAN HEALTH SOIL QUALITY GUIDELINES

The derivation of human health soil quality guidelines for TEX is outlined in the following sections for four land uses: agricultural, residential/parkland, commercial, and industrial. Various modifications to the CCME (1996) protocol which were used in the Canada-wide Standard for Petroleum Hydrocarbons in Soil (CCME 2000) were also applied in the development of these guidelines. Modifications include the derivation of guidelines for different soil textures (coarse and fine) and depths (surface soil and subsoil). As defined in the Canada-wide Standard for Petroleum Hydrocarbons, fine-grained soils are those which contain greater than 50% by mass, particles less than 75 µm mean diameter (D_{50} <75 µm). Coarse-grained soils are those which contain greater than 50% by mass, particles greater than 75 µm mean diameter (D_{50} >75 µm). Surface soil refers to the unconsolidated mineral material on the immediate surface of the earth that serves as a natural medium for terrestrial plant growth, and can extend as deep as 1.5 m. Subsoil is defined as the unconsolidated regolith material above the water table not subject to soil forming processes; this nominally includes vadose zone materials below 1.5 m depth. These human health soil quality guidelines for TEX will be considered along with the environmental guidelines in making final recommendations for Canadian Soil Quality Guidelines for the protection of environmental and human health (CCME 1996; see Chapter 8).

The overall human health soil quality guidelines (SQG_{HH}) were determined by considering four exposure pathways: soil ingestion, soil dermal contact, indoor vapour inhalation, and ingestion of contaminated groundwater. Two exposure pathways that are typically considered in deriving the SQG_{HH} , soil inhalation and off-site migration, were not calculated for TEX. Given the volatility and biodegradability of TEX, it is unlikely that significant amounts would remain after wind transport of soil, and so these two pathways were not evaluated. As noted in Chapter 3, both volatilization and sorption can affect the fate of TEX in soil, and the relative strength of the two processes will vary depending on characteristics of the particular soil (e.g., organic matter content) and on other environmental parameters (e.g., temperature). With airborne soil particles, however, it is expected that volatilization will play a greater role than adsorption in the fate of TEX.

Human Exposure Limits

Contrary to benzene, TEX have not been classified as human carcinogens by Health Canada (1996a). For non-carcinogens, inhalation exposure is assessed relative to a tolerable concentration (TC), while ingestion exposure is assessed relative to a tolerable daily intake (TDI).

For toluene the TDI of 0.22 $mg \cdot kg^{-1}$ $bw \cdot d^{-1}$ and the TC of 3.8 $mg \cdot m^{-3}$ are adopted directly from Health Canada (1996a). The oral TDI is based on a study by Huff (1990) that reported a NOEL of 312 mg·kg^{-1} bw·d^{-1} for increases in relative liver and kidney weight of male rats exposed for 13 weeks by gavage. The inhalation TC is based on a clinical study by Andersen et al. (1983) that reported an increase in neurological symptoms and irritation of the respiratory tract in human volunteers exposed to 375 mg·m^{-3} for 6 hours per day over four days. No adverse effects were observed in the volunteers at 150 mg·m^{-3}.

Health Canada has not developed TDI or TC values for ethylbenzene. However, the USEPA IRIS database (USEPA 1991) provides a reference dose (RfD) of 0.1 mg·kg^{-1} bw·d^{-1} and a reference concentration (RfC) of 1 mg·m^{-3} for ethylbenzene. These values are adopted as the TDI and TC, respectively for this project. The oral RfD is based on a study by Wolf et al. (1956) that examined histopathological changes in the kidney and liver of rats exposed to ethylbenzene through gavage. The inhalation RfC is based on studies by Andrew et al. (1981) and Hardin et al. (1981) that examined developmental toxicity of ethylbenzene to rats and rabbits.

For xylenes, the TDI of 1.5 mg·kg^{-1} bw·d^{-1} and the provisional TC of 0.18 mg·m^{-3} are adopted directly from Health Canada (1996a). The oral TDI is based on a study by Condie et al. (1988) which reported a NOAEL of 150 mg·kg^{-1} bw·d^{-1} for increases in the liver weight of rats exposed to xylenes administered by gavage over 90 days. The inhalation TC is based on a developmental study by Ungvary and Tatrai (1985) which reported a LOEL of 250 mg·m^{-3} for maternal toxicity and fetal skeletal retardation in rats exposed to xylenes on days 7 to 15 of gestation.

Background Exposure

The possibility of receptors being exposed to levels of TEX contamination in background soils was considered, and included in the equations used to calculated guidelines for human exposure pathways. However, as natural sources of TEX are relatively small, the background level of TEX in soil was assumed to be zero. Also, exposure to chemicals of concern can occur via other media than soil (*e.g.*, water, air, food, and consumer products) (CCME 1996). Accordingly, the soil quality guidelines incorporated a soil allocation factor (SAF) that was used to determine what fraction of the total acceptable exposure was allocated to exposure via contaminated soil. SAF values for TEX were assumed to be 0.5 (Appendix XV).

Soil Ingestion

The guidelines for this pathway are the same for coarse and fine soil. No subsoil quality guidelines are calculated for this pathway, based on the lack of direct contact to subsoils for most receptors. The SQG_{SI} for toluene, ethylbenzene and xylenes in surface soils, based on a toddler as the receptor, were calculated using the following equation:

$$SQG_{SI} = \frac{(TDI - EDI) \times SAF \times BW \times 10^{3}}{SIR \times AF_{G} \times ET} \quad + \quad [BSC]$$

where,

SQG_{SI} = human health soil quality guideline for soil ingestion ($mg \cdot kg^{-1}$);
BW = toddler body weight (Appendix XV);
TDI = tolerable daily intake (Appendix XVII);
EDI = estimated daily intake (Appendix XVII);
SAF = soil allocation factor (Appendix XV);
10^{3} = conversion factor from kg to g;
SIR = soil ingestion rate for the toddler (Appendix XV);
AF_{G} = absorption factor for gut (1; assumed);
ET = exposure term for toddler (Appendix XV); and
BSC = background soil concentration (Appendix XVII).

Substituting these values into the above equation and rounding to 2 significant figures yields a value of 22 000 $mg \cdot kg^{-1}$ for toluene, 10 000 $mg \cdot kg^{-1}$ for ethylbenzene and 150 000 $mg \cdot kg^{-1}$ for xylenes, which are the guidelines for incidental human soil ingestion of TEX for agricultural and residential/parkland land uses.

Soil Dermal Contact

The guidelines for this pathway are the same for coarse and fine soil. No subsoil quality guidelines are calculated for this pathway based on the lack of direct contact to subsoils for most receptors. The SQG_{DC} for toluene, ethylbenzene and xylenes in surface soils were calculated using the following equation:

$$SQG_{DC} = \frac{(TDI - EDI) \times SAF \times BW \times 10^{6}}{AF_{D} \times \{ (SA_{HANDS} \times DL_{HANDS}) + (SA_{OTHER} \times DL_{OTHER}) \} \times EF \times ET} \quad + \quad [BSC]$$

where,

SQG_{DC} = human health soil quality guideline for soil dermal contact ($mg \cdot kg^{-1}$);
BW = toddler body weight (Appendix XV);
TDI = tolerable daily intake (Appendix XVII);
EDI = estimated daily intake (Appendix XVII;
SAF = soil allocation factor (Appendix XV);
10^{6} = conversion factor from kg to mg;
AF_{D} = absorption factor for soil dermal contact (Appendix XVII);
SA_{hands} = toddler surface area of hands (Appendix XV);
DL_{hands} = dermal soil loading for toddler's hands (Appendix XV);
SA_{other} = toddler surface area for other exposed skin (Appendix XV);

DL_{other} = toddler dermal soil loading for other exposed skin (Appendix XV);
EF = exposure frequency (1 event·d^{-1});
ET = exposure term for toddler (Appendix XV); and,
BSC = background soil concentration (Appendix XVII).

Substituting these values into the above equation and rounding to 3 significant figures yields a value of 220 000 mg·kg^{-1} for toluene and 58 000 mg·kg^{-1} for ethylbenzene, which are the guidelines for incidental human soil dermal contact for agricultural and residential/parkland land uses. The SQG_{DC} value obtained for xylenes is greater than 1 000 000 mg·kg^{-1}.

Indoor Vapour Inhalation

The guidelines for this pathway are different for coarse and fine soil, and also for surface soil and subsoil. In addition, for the agricultural and residential land uses, different guidelines are calculated depending on whether the building has a basement, or is of slab-on-grade construction. For completeness, the soil quality guidelines for the indoor vapour inhalation pathway (SQG_{II}) for both construction types are calculated here; however, in all cases the slab-on-grade is the lower of the two. The SQG_{II} values for TEX are calculated using the following equations, and the appropriate parameter values from Appendices XV to XVIII.

$$SQG_{II} = \frac{(TC - C_a) \times [\theta_w + (K_{oc} \times f_{oc} \times \rho_b) + (H' \times \theta_a)] \times SAF \times DF_i \times 10^3}{H' \times \rho_b \times ET \times 10^6} + BSC$$

where,

SQG_{II} = soil quality guideline for indoor infiltration (mg·kg^{-1});
TC = tolerable concentration (Appendix XVII);
C_a = background indoor air concentration (Appendix XVII);
θ_w = moisture-filled porosity (Appendix XVI);
K_{oc} = organic carbon partition coefficient (Appendix XVII);
f_{oc} = fraction organic carbon (Appendix XV);
ρ_b = dry soil bulk density (Appendix XVI);
H' = dimensionless Henry's Law Constant (Appendix XVII);
θ_a = vapour-filled porosity (Appendix XVI);
SAF = soil allocation factor (Appendix XV);
DF_i = dilution factor from soil gas to indoor air (calculation below);
10^3 = conversion factor from kg to g;
ET = exposure term (Appendix XV);
10^6 = conversion factor from m^3 to cm^3; and,
BSC = background soil concentration (Appendix XVII).

Substituting these values in the above equation and rounding to 2 significant figures yields SQG_{II} values for toluene on agricultural and residential/parkland, with slab-on grade construction, of 120 mg·kg^{-1} for coarse surface soil, 140 mg·kg^{-1} for coarse subsoil, 2700 mg·kg^{-1} for fine surface soil and 2 800 mg·kg^{-1} for fine subsoil. For ethylbenzene on agricultural and residential/parkland with slab-on-grade construction, the SQG_{II} values are 55 $mg \cdot kg^{-1}$ for coarse surface soil, 63 $mg \cdot kg^{-1}$ for coarse subsoil, 1300 $mg \cdot kg^{-1}$ for fine surface soil and 1400 $mg \cdot kg^{-1}$ for fine subsoil. For xylenes on agricultural and residential/parkland with slab-on-grade construction, the SQG_{II} values are 14 $mg \cdot kg^{-1}$ for coarse surface soil, 16 $mg \cdot kg^{-1}$ for coarse subsoil, 320 $mg \cdot kg^{-1}$ for fine surface soil and 340 $mg \cdot kg^{-1}$ for fine subsoil.

Dilution Factor

The dilution factor (DF_i) was calculated as follows:

$$DF_i = \frac{1}{\alpha}$$

where,

DF_i = dilution factor from soil gas concentration to indoor air concentration (unitless); and,

α = attenuation coefficient (unitless; see derivation below).

Calculation of α for Coarse Soils

The attenuation coefficients for coarse soils were calculated using the following equations:

$$\alpha = \frac{\left(\frac{D_T^{eff} \times A_B}{Q_B \times L_T}\right)}{\left(\frac{D_T^{eff} \times A_B}{Q_{soil} \times L_T}\right) + 1}$$

$$D_T^{eff} = D_a \times \left(\frac{\theta_a^{10/3}}{\theta_t^2}\right)$$

$$A_B = (L_B W_B) + 2Z_{crack} \times (L_B + W_B)$$

$$Q_B = \frac{L_B W_B H_B ACH}{3600}$$

$$Q_{soil} = \frac{2\pi \Delta P k_v X_{crack}}{\mu \ln\left[\frac{2Z_{crack}}{r_{crack}}\right]}$$

where,

α = attenuation coefficient (unitless);
D_T^{eff} = effective porous media diffusion coefficient based on vapour-phase concentrations for the region between the source and foundation (calculated above);
A_B = below ground building area (calculated above);
Q_B = building ventilation rate (calculated above);
L_T = distance from contaminant source to foundation (Appendix XVIII);
Q_{soil} = volumetric flow rate of soil gas into the building (calculated above);
D_a = diffusion coefficient in air (Appendix XVII);
θ_a = soil vapour-filled porosity (Appendix XVI);
θ_t = soil total porosity (Appendix XVI);
L_B = building length (Appendix XVIII);
W_B = building width (Appendix XVIII);
H_B = building height (Appendix XVIII);
ACH = air exchanges per hour (Appendix XVIII);
3600 = conversion factor from hours to seconds
ΔP = pressure differential (Appendix XVIII);
k_v = soil vapour permeability to vapour flow (Appendix XVI);
X_{crack} = length of idealized cylinder (Appendix XVIII);
μ = vapour viscosity (Appendix XVII);
Z_{crack} = distance below grade to idealized cylinder (Appendix XVIII); and,
r_{crack} = radius of idealized cylinder (Appendix XVIII).

Substituting these values in the above equations yields α values for toluene on agricultural and residential/parkland lands of 7.169×10^{-5} in coarse surface soils and 6.348×10^{-5} for coarse subsoils. The α values for ethylbenzene on agricultural and residential/parkland soils are 7.128×10^{-5} for coarse surface soils and 6.203×10^{-5} for coarse subsoils. Xylenes on agricultural and residential/parkland soils have α values of 7.140×10^{-5} for coarse surface soils and 6.243×10^{-5} for coarse subsoils.

Calculation of α for Fine Soils

The attenuation coefficients for fine soils were calculated using the following equations:

$$\alpha = \frac{\left(\dfrac{D_T^{eff} \times A_B}{Q_B \times L_T}\right)}{1 + \left(\dfrac{D_T^{eff} \times A_B}{Q_B \times L_T}\right) + \left(\dfrac{D_T^{eff} \times A_B \times L_{crack}}{D_{crack} \times A_{crack} \times L_T}\right)}$$

$$D_T^{eff} = D_a \times \left(\frac{\theta_a^{10/3}}{\theta_t^2}\right)$$

where,

α = attenuation coefficient (unitless);

D_T^{eff} = effective porous media diffusion coefficient based on vapour-phase concentrations for the region between the source and foundation (calculated above);
A_B = below ground building area (calculated above);
Q_B = building ventilation rate (calculated above);
L_T = distance from contaminant source to foundation (Appendix XVIII);
L_{crack} = thickness of the foundation (Appendix XVIII);
D_{crack} = effective diffusion coefficient through the crack; it is assumed that the cracks are filled with coarse soil, and accordingly D_{crack} is D_T^{eff} for coarse soils (Appendix XVIII);
A_{crack} = area of cracks through which contaminant vapours enter building (Appendix XVIII);
D_a = diffusion coefficient in air (Appendix XVII);
θ_a = soil vapour-filled porosity (Appendix XVI); and,
θ_t = soil total porosity (Appendix XVI).

Substituting these values in the above equations yields α values for toluene on agricultural and residential/parkland lands, of 3.3956×10^{-6} for fine surface soils and 3.2564×10^{-6} for fine subsoils. The α values for ethylbenzene on agricultural and residential/parkland soils are 2.927×10^{-6} for fine surface soils and 2.807×10^{-6} for fine subsoils. Xylenes on agricultural and residential/parkland soils have α values of 3.044×10^{-6} for fine surface soils and 2.919×10^{-6} for fine subsoils.

Protection of Potable Groundwater

The groundwater check values for the protection of potable (drinking) water for TEX are calculated using the formula from the PHC CWS, adapted to use the Canadian Drinking Water Quality Guidelines (Health Canada 1996b) as the toxicological basis, rather than the TDI. Groundwater check values are calculated separately for coarse and fine soils, but for soils of the same texture, the check values do not differ between surface and subsoil nor across different land uses. The check values are calculated using the following equations:

$$GWC_P = WQG_{DW} \times \left[K_d + \left(\frac{\theta_m}{\rho_w} \right) \right] \times DF_w$$

$$K_d = K_{oc} \times f_{oc}$$

$$DF_w = \frac{B \times K \times i}{I \times L} + 1$$

where,

GWC_P = groundwater check for the protection of potable water ($mg \cdot kg^{-1}$);
WQG_{DW} = drinking water quality guideline (Appendix XVII);
K_d = chemical-specific distribution coefficient (calculated above);
K_{oc} = organic carbon partition coefficient (Appendix XVII);
f_{oc} = fraction organic carbon (Appendix XV);
θ_m = soil water content (Appendix XVI);
ρ_w = density of water (Appendix XV);
DF_w = groundwater/pore water dilution factor (unitless) (calculated above);
B = effective mixing depth in aquifer (Appendix XV);
K = saturated hydraulic conductivity of aquifer (Appendix XVI);
i = hydraulic gradient (Appendix XV);
I = infiltration (recharge) rate (Appendix XVI); and,
L = site length (Appendix XV).

Substituting these values into the above equations yields values of 0.37 $mg \cdot kg^{-1}$ for coarse soil and 0.08 $mg \cdot kg^{-1}$ for fine soil for toluene in all four land uses. These values are the groundwater check values for the protection of potable (drinking) groundwater for toluene. The resulting groundwater check values for the protection of potable groundwater for ethylbenzene in all four land uses are 0.082 $mg \cdot kg^{-1}$ for coarse soil and 0.018 $mg \cdot kg^{-1}$ for fine soil. For xylenes in all four land uses, the groundwater check values are 11 $mg \cdot kg^{-1}$ for coarse soil and 2.4 $mg \cdot kg^{-1}$ for fine soil.

Final Human Health Soil Quality Guidelines

The final human health soil quality guidelines (SQG_{HH}) for TEX for the two soil textures and two soil depths in each of the four land uses are presented in Tables 2 to 7. The SQG_{HH} is based on the most sensitive of the various guidelines and check values calculated for human health. For coarse and fine soils on all land uses, the most sensitive pathway is the groundwater check for drinking water. Therefore, for toluene, the SQG_{HH} values in all land uses for surface soils and subsoils, are 0.37 and 0.08 $mg \cdot kg^{-1}$, respectively. For ethylbenzene, the SQG_{HH} values in all land uses for surface soils and subsoils, are 0.082 and 0.018 $mg \cdot kg^{-1}$, respectively. Finally, for xylenes, the SQG_{HH} values in all land uses for surface soils and subsoils, are 11 and 2.4 $mg \cdot kg^{-1}$, respectively.

CHAPTER 8. RECOMMENDED CANADIAN SOIL QUALITY GUIDELINES

According to the formal protocol (CCME 1996), both environmental and human health soil quality guidelines are developed for four land uses: agricultural, residential/parkland, commercial, and industrial. The lowest value generated by the two approaches for each of the four land uses is recommended by the CCME as the Canadian Soil Quality Guideline. The environmental soil quality guidelines for toluene, ethylbenzene, and xylenes, presented in Chapter 6, were considered along with the human health guidelines, presented in Chapter 7 in making final recommendations for Canadian Soil Quality Guidelines for the protection of environmental and human health. The recommended Canadian Soil Quality Guidelines for the protection of environmental and human health (CCME 1999) are presented below in Tables 2 to 7. The interim remediation criteria (CCME 1991) are also presented for comparison purposes.

Table 2. Soil quality guidelines and check values for toluene ($\mathrm{mg \cdot kg^{-1}}$) in surface soil.

SURFACE SOIL	Agricultural		Residential/ parkland		Commercial		Industrial	
	Coarse	Fine	Coarse	Fine	Coarse	Fine	Coarse	Fine
Guideline	**0.37[a]**	**0.08[a]**	**0.37[a]**	**0.08[a]**	**0.37[a]**	**0.08[a]**	**0.37[a]**	**0.08[a]**
Human health guidelines/check values								
$\mathrm{SQG}_{\mathrm{HH}}$	0.37[b]	0.08[b]	0.37[b]	0.08[b]	0.37[b]	0.08[b]	0.37[b]	0.08[b]
Soil ingestion guideline	22 000	22 000	22 000	22 000	82 000	82 000	NA	NA
Soil dermal contact guideline	220 000	220 000	220 000	220 000	790 000	790 000	NA	NA
Soil inhalation guideline	NC	NC	NC	NC	NC	NC	NC	NC
Inhalation of indoor air check (basement)	200	2 600	200	2 600	—	—	—	—
Inhalation of indoor air check (slab-on-grade)	120	2 700	120	2 700	1 400	13 000	1 400	13 000
Off-site migration check	—	—	—	—	—	—	NC[c]	NC[c]
Groundwater check (drinking water)	0.37	0.08	0.37	0.08	0.37	0.08	0.37	0.08
Produce, meat, and milk check	NC[d]	NC[d]	NC[d]	NC[d]	—	—	—	—
Environmental health guidelines/check values								
$\mathrm{SQG}_{\mathrm{E}}$	75[e]	110[e]	75[f]	110[f]	250[f]	330[f]	250[f]	330[f]
Soil contact guideline	75	110	75	110	250	330	250	330
Soil and food ingestion guideline	1,400	1,400	—	—	—	—	—	—
Nutrient and energy cycling check[g]	NC	NC	NC	NC	NC	NC	NC	NC
Off-site migration check	—	—	—	—	—	—	NC[c]	NC[c]
Groundwater check (livestock)	1 800[h]	NC[i]	—	—	—	—	—	—
Groundwater check (aquatic life)	0.1[j]	NC[i]	0.1[j]	NC[i]	0.1[j]	NC[i]	0.1[j]	NC[i]
Interim soil quality criterion (CCME 1991)	0.1		3		30		30	

Notes: NA= calculated guideline >1 000 000 $\mathrm{mg \cdot kg^{-1}}$; NC = not calculated; $\mathrm{SQG}_{\mathrm{E}}$ = soil quality guideline for environmental health; $\mathrm{SQG}_{\mathrm{HH}}$ = soil quality guideline for human health. The dash indicates a guideline/check value that is not part of the exposure scenario for this land use and therefore is not calculated.

[a] Data are sufficient and adequate to calculate an $\mathrm{SQG}_{\mathrm{HH}}$ and an $\mathrm{SQG}_{\mathrm{E}}$. Therefore the soil quality guideline is the lower of the two and represents a fully integrated *de novo* guideline for this land use, derived in accordance with the soil protocol (CCME 1996). The corresponding interim soil quality criterion (CCME 1991) is superseded by the soil quality guideline.

[b] The $\mathrm{SQG}_{\mathrm{HH}}$ is the lowest of the human health guidelines and check values.

[c] Given the volatility and biodegradability of toluene, it is unlikely that significant amounts would remain after wind or water transport of soil, and so this pathway was not evaluated.

[d] This check is intended to protect against chemicals that may bioconcentrate in human food. Toluene is not expected to exhibit this behaviour, and so this pathway was not evaluated.

[e] The $\mathrm{SQG}_{\mathrm{E}}$ is based on the lower of the soil contact guideline and the soil and food ingestion guideline.

[f] The $\mathrm{SQG}_{\mathrm{E}}$ is based on the soil contact guideline.

[g] Data are insufficient/inadequate to calculate the nutrient and energy cycling check for this land use.

[h] This environmental groundwater check value is provisional because at the time of derivation there was no Canadian Water Quality Guideline for the protection of livestock watering for toluene upon which to base it. For details on the derivation, see Chapter 6. This check value is not used in determining the national soil quality guideline, but is provided as a reference for site-specific application.

[i] The environmental groundwater check value has not been determined because calculations show that in 100 years groundwater migration through fine soils will be less than 10 metres. For site-specific calculations where the protection of potable groundwater pathway is active, a hydraulic conductivity of 32 $\mathrm{m \cdot y^{-1}}$ should be assumed, if adequate measured data are not available.

[j] This environmental groundwater check value is not used in determining the national soil quality guideline, but is provided as a reference for site-specific application.

Table 3. Soil quality guidelines and check values for toluene (mg·kg^{-1}) in subsoil.

SUBSOIL	Agricultural		Residential/ parkland		Commercial		Industrial	
	Coarse	Fine	Coarse	Fine	Coarse	Fine	Coarse	Fine
Guideline	**0.37[a]**	**0.08[a]**	**0.37[a]**	**0.08[a]**	**0.37[a]**	**0.08[a]**	**0.37[a]**	**0.08[a]**
Human health guidelines/check values								
SQG_{HH}	0.37[b]	0.08[b]	0.37[b]	0.08[b]	0.37[b]	0.08[b]	0.37[b]	0.08[b]
Soil ingestion guideline	NC	NC	NC	NC	NC	NC	NC	NC
Soil dermal contact guideline	NC	NC	NC	NC	NC	NC	NC	NC
Soil inhalation guideline	NC	NC	NC	NC	NC	NC	NC	NC
Inhalation of indoor air check (basement)	200	2 600	200	2 600	—	—	—	—
Inhalation of indoor air check (slab-on-grade)	140	2 800	140	2 800	1 500	13 000	1 500	13 000
Off-site migration check	—	—	—	—	—	—	NC[c]	NC[c]
Groundwater check (drinking water)	0.37	0.08	0.37	0.08	0.37	0.08	0.37	0.08
Produce, meat, and milk check	NC[d]	NC[d]	NC[d]	NC[d]	—	—	—	—
Environmental health guidelines/check values								
SQG_E	150[e]	220[e]	150[f]	220[f]	500[f]	660[f]	500[f]	660[f]
Soil contact guideline	150	220	150	220	500	660	500	660
Soil and food ingestion guideline	NC	NC	—	—	—	—	—	—
Nutrient and energy cycling check	NC[g]	NC[g]	NC[g]	NC[g]	NC[g]	NC[g]	NC[g]	NC[g]
Off-site migration check	—	—	—	—	—	—	NC[c]	NC[c]
Groundwater check (livestock)	1 800[h]	NC[i]	—	—	—	—	—	—
Groundwater check (aquatic life)	0.1[j]	NC[i]	0.1[j]	NC[i]	0.1[j]	NC[i]	0.1[j]	NC[i]
Interim soil quality criterion (CCME 1991)	0.1		3		30		30	

Notes: NC = not calculated; SQG_E = soil quality guideline for environmental health; SQG_{HH} = soil quality guideline for human health. The dash indicates a guideline/check value that is not part of the exposure scenario for this land use and therefore is not calculated.

[a] Data are sufficient and adequate to calculate an SQG_{HH} and an SQG_E. Therefore the soil quality guideline is the lower of the two and represents a fully integrated *de novo* guideline for this land use, derived in accordance with the soil protocol (CCME 1996). The corresponding interim soil quality criterion (CCME 1991) is superseded by the soil quality guideline.

[b] The SQG_{HH} is the lowest of the human health guidelines and check values.

[c] Given the volatility and biodegradability of toluene, it is unlikely that significant amounts would remain after wind or water transport of soil, and so this pathway was not evaluated.

[d] This check is intended to protect against chemicals that may bioconcentrate in human food. Toluene is not expected to exhibit this behaviour, and so this pathway was not evaluated.

[e] The SQG_E is based on the lower of the soil contact guideline and the soil and food ingestion guideline.

[f] The SQG_E is based on the soil contact guideline.

[g] Data are insufficient/inadequate to calculate the nutrient and energy cycling check for this land use.

[h] This environmental groundwater check value is provisional because at the time of derivation there was no Canadian Water Quality Guideline for the protection of livestock watering for toluene upon which to base it. For details on the derivation, see Chapter 6. This check value is not used in determining the national soil quality guideline, but is provided as a reference for site-specific application.

[i] The environmental groundwater check value has not been determined because calculations show that in 100 years groundwater migration through fine soils will be less than 10 metres. For site-specific calculations where the protection of potable groundwater pathway is active, a hydraulic conductivity of 32 m·y^{-1} should be assumed, if adequate measured data are not available.

[j] This environmental groundwater check value is not used in determining the national soil quality guideline, but is provided as a reference for site-specific application.

Table 4. Soil quality guidelines and check values for ethylbenzene ($mg\cdot kg^{-1}$) in surface soil.

SURFACE SOIL	Agricultural		Residential/ parkland		Commercial		Industrial	
	Coarse	Fine	Coarse	Fine	Coarse	Fine	Coarse	Fine
Guideline	**0.082[a]**	**0.018[a]**	**0.082[a]**	**0.018[a]**	**0.082[a]**	**0.018[a]**	**0.082[a]**	**0.018[a]**
Human health guidelines/check values								
SQG_{HH}	0.082[b]	0.018[b]	0.082[b]	0.018[b]	0.082[b]	0.018[b]	0.082[b]	0.018[b]
Soil ingestion guideline	10 000	10 000	10 000	10 000	36 000	36 000	620 000	620 000
Soil dermal contact guideline	58 000	58 000	58 000	58 000	210 000	210 000	560 000	560 000
Soil inhalation guideline	NC	NC	NC	NC	NC	NC	NC	NC
Inhalation of indoor air check (basement)	88	1 300	88	1 300	—	—	—	—
Inhalation of indoor air check (slab-on-grade)	55	1 300	55	1 300	630	6 500	630	6 500
Off-site migration check	—	—	—	—	—	—	NC[c]	NC[c]
Groundwater check (drinking water)	0.082	0.018	0.082	0.018	0.082	0.018	0.082	0.018
Produce, meat, and milk check	NC[d]	NC[d]	NC[d]	NC[d]	—	—	—	—
Environmental health guidelines/check values								
SQG_E	55[e]	120[e]	55[f]	120[f]	300[f]	430[f]	300[f]	430[f]
Soil contact guideline	55	120	55	120	300	430	300	430
Soil and food ingestion guideline	910	910	—	—	—	—	—	—
Nutrient and energy cycling check [g]	NC	NC	NC	NC	NC	NC	NC	NC
Off-site migration check	—	—	—	—	—	—	NC[c]	NC[c]
Groundwater check (livestock)	13 000[h]	NC[i]	—	—	—	—	—	—
Groundwater check (aquatic life)	50[j]	NC[i]	50[j]	NC[i]	50[j]	NC[i]	50[j]	NC[i]
Interim soil quality criterion (CCME 1991)	0.1		5		50		50	

Notes: NC = not calculated; SQG_E = soil quality guideline for environmental health; SQG_{HH} = soil quality guideline for human health. The dash indicates a guideline/check value that is not part of the exposure scenario for this land use and therefore is not calculated.

[a] Data are sufficient and adequate to calculate an SQG_{HH} and an SQG_E. Therefore the soil quality guideline is the lower of the two and represents a fully integrated *de novo* guideline for this land use, derived in accordance with the soil protocol (CCME 1996). The corresponding interim soil quality criterion (CCME 1991) is superseded by the soil quality guideline.

[b] The SQG_{HH} is the lowest of the human health guidelines and check values.

[c] Given the volatility and biodegradability of ethylbenzene, it is unlikely that significant amounts would remain after wind or water transport of soil, and so this pathway was not evaluated.

[d] This check is intended to protect against chemicals that may bioconcentrate in human food. Ethylbenzene is not expected to exhibit this behaviour, and so this pathway was not evaluated.

[e] The SQG_E is based on the lower of the soil contact guideline and the soil and food ingestion guideline.

[f] The SQG_E is based on the soil contact guideline.

[g] Data are insufficient/inadequate to calculate the nutrient and energy cycling check for this land use.

[h] This environmental groundwater check value is provisional because at the time of derivation there was no Canadian Water Quality Guideline for the protection of livestock watering for ethylbenzene upon which to base it. For details on the derivation, see Chapter 6. This check value is not used in determining the national soil quality guideline, but is provided as a reference for site-specific application.

[i] The environmental groundwater check value has not been determined because calculations show that in 100 years groundwater migration through fine soils will be less than 10 metres. For site-specific calculations where the protection of potable groundwater pathway is active, a hydraulic conductivity of $32\ m\cdot y^{-1}$ should be assumed, if adequate measured data are not available.

[j] This environmental groundwater check value is not used in determining the national soil quality guideline, but is provided as a reference for site-specific application.

Table 5. Soil quality guidelines and check values for ethylbenzene ($mg\cdot kg^{-1}$) in subsoil.

SUBSOIL	Agricultural		Residential/ parkland		Commercial		Industrial	
	Coarse	Fine	Coarse	Fine	Coarse	Fine	Coarse	Fine
Guideline	**0.082[a]**	**0.018[a]**	**0.082[a]**	**0.018[a]**	**0.082[a]**	**0.018[a]**	**0.082[a]**	**0.018[a]**
Human health guidelines/check values								
SQG_{HH}	0.082[b]	0.018[b]	0.082[b]	0.018[b]	0.082[b]	0.018[b]	0.082[b]	0.018[b]
Soil ingestion guideline	NC	NC	NC	NC	NC	NC	NC	NC
Soil dermal contact guideline	NC	NC	NC	NC	NC	NC	NC	NC
Soil inhalation guideline	NC	NC	NC	NC	NC	NC	NC	NC
Inhalation of indoor air check (basement)	88	1 300	88	1 300	—	—	—	—
Inhalation of indoor air check (slab-on-grade)	63	1 400	63	1 400	670	6 700	670	6 700
Off-site migration check	—	—	—	—	—	—	NC[c]	NC[c]
Groundwater check (drinking water)	0.082	0.018	0.082	0.018	0.082	0.018	0.082	0.018
Produce, meat, and milk check	NC[d]	NC[d]	NC[d]	NC[d]	—	—	—	—
Environmental health guidelines/check values								
SQG_E	110[e]	240[e]	110[f]	240[f]	600[f]	860[f]	600[f]	860[f]
Soil contact guideline	110	240	110	240	600	860	600	860
Soil and food ingestion guideline	NC	NC	—	—	—	—	—	—
Nutrient and energy cycling check	NC[g]	NC[g]	NC[g]	NC[g]	NC[g]	NC[g]	NC[g]	NC[g]
Off-site migration check	—	—	—	—	—	—	NC[c]	NC[c]
Groundwater check (livestock)	13 000[h]	NC[i]	—	—	—	—	—	—
Groundwater check (aquatic life)	50[j]	NC[i]	50[j]	NC[i]	50[j]	NC[i]	50[j]	NC[i]
Interim soil quality criterion (CCME 1991)	0.1		5		50		50	

Notes: NC = not calculated; SQG_E = soil quality guideline for environmental health; SQG_{HH} = soil quality guideline for human health. The dash indicates a guideline/check value that is not part of the exposure scenario for this land use and therefore is not calculated.

[a] Data are sufficient and adequate to calculate an SQG_{HH} and an SQG_E. Therefore the soil quality guideline is the lower of the two and represents a fully integrated *de novo* guideline for this land use, derived in accordance with the soil protocol (CCME 1996). The corresponding interim soil quality criterion (CCME 1991) is superseded by the soil quality guideline.

[b] The SQG_{HH} is the lowest of the human health guidelines and check values.

[c] Given the volatility and biodegradability of ethylbenzene, it is unlikely that significant amounts would remain after wind or water transport of soil, and so this pathway was not evaluated.

[d] This check is intended to protect against chemicals that may bioconcentrate in human food. Ethylbenzene is not expected to exhibit this behaviour, and so this pathway was not evaluated.

[e] The SQG_E is based on the lower of the soil contact guideline and the soil and food ingestion guideline.

[f] The SQG_E is based on the soil contact guideline.

[g] Data are insufficient/inadequate to calculate the nutrient and energy cycling check for this land use.

[h] This environmental groundwater check value is provisional because at the time of derivation there was no Canadian Water Quality Guideline for the protection of livestock watering for ethylbenzene upon which to base it. For details on the derivation, see Chapter 6. This check value is not used in determining the national soil quality guideline, but is provided as a reference for site-specific application.

[i] The environmental groundwater check value has not been determined because calculations show that in 100 years groundwater migration through fine soils will be less than 10 metres. For site-specific calculations where the protection of potable groundwater pathway is active, a hydraulic conductivity of 32 $m\cdot y^{-1}$ should be assumed, if adequate measured data are not available.

[j] This environmental groundwater check value is not used in determining the national soil quality guideline, but is provided as a reference for site-specific application.

Table 6. Soil quality guidelines and check values for xylenes ($mg{\cdot}kg^{-1}$) in surface soil.

SURFACE SOIL	Agricultural		Residential/ parkland		Commercial		Industrial	
	Coarse	Fine	Coarse	Fine	Coarse	Fine	Coarse	Fine
Guideline	**11^a**	**2.4^a**	**11^a**	**2.4^a**	**11^a**	**2.4^a**	**11^a**	**2.4^a**
Human health guidelines/check values								
SQG_{HH}	11^b	2.4^b	11^b	2.4^b	11^b	2.4^b	11^b	2.4^b
Soil ingestion guideline	150 000	150 000	150 000	150 000	560 000	560 000	NA	NA
Soil dermal contact guideline	NA	NA	NA	NA	NA	NA	NA	NA
Soil inhalation guideline	NC	NC	NC	NC	NC	NC	NC	NC
Inhalation of indoor air check (basement)	22	320	22	320	—	—	—	—
Inhalation of indoor air check (slab-on-grade)	14	320	14	320	160	1 600	160	1 600
Off-site migration check	—	—	—	—	—	—	NC^c	NC^c
Groundwater check (drinking water)	11	2.4	11	2.4	11	2.4	11	2.4
Produce, meat, and milk check	NC^d	NC^d	NC^d	NC^d	—	—	—	—
Environmental health guidelines/check values								
SQG_E	95^e	65^e	95^f	65^f	350^f	230^f	350^f	230^f
Soil contact guideline	95	65	95	65	350	230	350	230
Soil and food ingestion guideline	3 700	3 700	—	—	—	—	—	—
Nutrient and energy cycling check [g]	NC	NC	NC	NC	NC	NC	NC	NC
Off-site migration check	—	—	—	—	—	—	NC^c	NC^c
Groundwater check (livestock)	$20\,000^h$	NC^i	—	—	—	—	—	—
Groundwater check (aquatic life)	37^j	NC^i	37^j	NC^i	37^j	NC^i	37^j	NC^i
Interim soil quality criterion (CCME 1991)	0.1		5		50		50	

Notes: NA= calculated guideline >1 000 000 $mg{\cdot}kg^{-1}$; NC = not calculated; SQG_E = soil quality guideline for environmental health; SQG_{HH} = soil quality guideline for human health. The dash indicates a guideline/check value that is not part of the exposure scenario for this land use and therefore is not calculated.

[a] Data are sufficient and adequate to calculate an SQG_{HH} and an SQG_E. Therefore the soil quality guideline is the lower of the two and represents a fully integrated *de novo* guideline for this land use, derived in accordance with the soil protocol (CCME 1996). The corresponding interim soil quality criterion (CCME 1991) is superseded by the soil quality guideline.

[b] The SQG_{HH} is the lowest of the human health guidelines and check values.

[c] Given the volatility and biodegradability of xylenes, it is unlikely that significant amounts would remain after wind or water transport of soil, and so this pathway was not evaluated.

[d] This check is intended to protect against chemicals that may bioconcentrate in human food. Xylenes are not expected to exhibit this behaviour, and so this pathway was not evaluated.

[e] The SQG_E is based on the lower of the soil contact guideline and the soil and food ingestion guideline.

[f] The SQG_E is based on the soil contact guideline.

[g] Data are insufficient/inadequate to calculate the nutrient and energy cycling check for this land use.

[h] This environmental groundwater check value is provisional because at the time of derivation there was no Canadian Water Quality Guideline for the protection of livestock watering for xylenes upon which to base it. For details on the derivation, see Chapter 6. This check value is not used in determining the national soil quality guideline, but is provided as a reference for site-specific application.

[i] The environmental groundwater check value has not been determined because calculations show that in 100 years groundwater migration through fine soils will be less than 10 metres. For site-specific calculations where the protection of potable groundwater pathway is active, a hydraulic conductivity of 32 $m{\cdot}y^{-1}$ should be assumed, if adequate measured data are not available.

[j] This environmental groundwater check value is provisional because at the time of derivation there was no Canadian Water Quality Guideline for the protection of aquatic life for xylenes upon which to base it. For details on the derivation, see Komex (2002). This environmental groundwater check value is not used in determining the national soil quality guideline, but is provided as a reference for site-specific application.

Table 7. Soil quality guidelines and check values for xylenes (mg·kg^{-1}) in subsoil.

SUBSOIL	Agricultural		Residential/ parkland		Commercial		Industrial	
	Coarse	Fine	Coarse	Fine	Coarse	Fine	Coarse	Fine
Guideline	**11[a]**	**2.4[a]**	**11[a]**	**2.4[a]**	**11[a]**	**2.4[a]**	**11[a]**	**2.4[a]**
Human health guidelines/check values								
SQG_{HH}	11[b]	2.4[b]	11[b]	2.4[b]	11[b]	2.4[b]	11[b]	2.4[b]
Soil ingestion guideline	NC	NC	NC	NC	NC	NC	NC	NC
Soil dermal contact guideline	NC	NC	NC	NC	NC	NC	NC	NC
Soil inhalation guideline	NC	NC	NC	NC	NC	NC	NC	NC
Inhalation of indoor air check (basement)	22	320	22	320	—	—	—	—
Inhalation of indoor air check (slab-on-grade)	16	340	16	340	170	1 600	170	1 600
Off-site migration check	—	—	—	—	—	—	NC[c]	—
Groundwater check (drinking water)	11	2.4	11	2.4	11	2.4	11	2.4
Produce, meat, and milk check	NC[d]	NC[d]	NC[d]	NC[d]	—	—	—	—
Environmental health guidelines/check values								
SQG_E	190[e]	130[e]	190[f]	130[f]	700[f]	460[f]	700[f]	460[f]
Soil contact guideline	190	130	190	130	700	460	700	460
Soil and food ingestion guideline	NC	NC	—	—	—	—	—	—
Nutrient and energy cycling check [g]	NC	NC	NC	NC	NC	NC	NC	NC
Off-site migration check	—	—	—	—	—	—	NC[c]	NC[c]
Groundwater check (livestock)	20 000[h]	NC[i]	—	—	—	—	—	—
Groundwater check (aquatic life)	37[j]	NC[i]	37[j]	NC[i]	37[j]	NC[i]	37[j]	NC[i]
Interim soil quality criterion (CCME 1991)	0.1		5		50		50	

Notes: NC = not calculated; SQG_E = soil quality guideline for environmental health; SQG_{HH} = soil quality guideline for human health. The dash indicates a guideline/check value that is not part of the exposure scenario for this land use and therefore is not calculated.

[a] Data are sufficient and adequate to calculate an SQG_{HH} and an SQG_E. Therefore the soil quality guideline is the lower of the two and represents a fully integrated *de novo* guideline for this land use, derived in accordance with the soil protocol (CCME 1996). The corresponding interim soil quality criterion (CCME 1991) is superseded by the soil quality guideline.

[b] The SQG_{HH} is the lowest of the human health guidelines and check values.

[c] Given the volatility and biodegradability of xylenes, it is unlikely that significant amounts would remain after wind or water transport of soil, and so this pathway was not evaluated.

[d] This check is intended to protect against chemicals that may bioconcentrate in human food. Xylenes are not expected to exhibit this behaviour, and so this pathway was not evaluated.

[e] The SQG_E is based on the lower of the soil contact guideline and the soil and food ingestion guideline.

[f] The SQG_E is based on the soil contact guideline.

[g] Data are insufficient/inadequate to calculate the nutrient and energy cycling check for this land use.

[h] This environmental groundwater check value is provisional because at the time of derivation there was no Canadian Water Quality Guideline for the protection of livestock watering for xylenes upon which to base it. For details on the derivation, see Chapter 6. This check value is not used in determining the national soil quality guideline, but is provided as a reference for site-specific application.

[i] The environmental groundwater check value has not been determined because calculations show that in 100 years groundwater migration through fine soils will be less than 10 metres. For site-specific calculations where the protection of potable groundwater pathway is active, a hydraulic conductivity of 32 m·y^{-1} should be assumed, if adequate measured data are not available.

[j] This environmental groundwater check value is provisional because at the time of derivation there was no Canadian Water Quality Guideline for the protection of aquatic life for xylenes upon which to base it. For details on the derivation, see Komex (2002). This environmental groundwater check value is not used in determining the national soil quality guideline, but is provided as a reference for site-specific application.

CHAPTER 9. AREAS FOR FUTURE RESEARCH

The guidelines developed in this document are based on the best available data. In the process of deriving these guidelines, however, it was noted that there are certain areas of study in which limited data are available for toluene, ethylbenzene, and xylenes. This chapter highlights some of the gaps in our knowledge for these substances with the hope that it will provide stimulation and direction for further research.

The soil quality guidelines for environmental health recommended in this document are based on limited toxicity data for soil invertebrates and terrestrial plants. Studies on additional species would be useful. In particular, additional studies on earthworms would be informative as they appear to be especially sensitive to these chemicals. Our understanding of TEX toxicity would also benefit from studies examining chronic effects in plants and chronic non-lethal effects (such as reductions in growth or reproduction) in invertebrates.

There is a lack of studies on the toxic effects of TEX on livestock, mammalian wildlife, and birds. Also needed are studies on the metabolism of TEX in mammals and birds, as well as invertebrates.

Nutrient and energy cycling checks could not be calculated for TEX due to a lack of data on microbial processes. Research is needed into the effects of these chemicals on nitrogen fixation, nitrification, nitrogen mineralization, decomposition, and respiration.

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APPENDIX I. PHYSICAL AND CHEMICAL PROPERTIES OF TEX COMPOUNDS

Property	Toluene	Ethylbenzene	Xylenes		
			o-xylene	*m*-xylene	*p*-xylene
Synonyms	Toluol phenylmethane methylbenzene methylbenzol antasal-1a	Ethylbenzol phenylethane	Xylol, ortho-xylene, 1,2-dimethylbenzene	Xylol, meta-xylene, 1,3-dimethylbenzene	Xylol, para-xylene, 1,4-dimethylbenzene
CAS registry number	108-88-3	100-41-4	95-47-6	108-38-3	106-42-3
Molecular formula	$C_6H_5CH_3$	$C_2H_5C_6H_5$	$C_6H_4(CH_3)_2$	$C_6H_4(CH_3)_2$	$C_6H_4(CH_3)_2$
Molecular weight	92.13	106.17	106.16	106.16	106.16
Physical state (20^0C)	liquid	liquid	liquid	liquid	liquid
Melting point (^0C)	- 95.0	-94.97	- 25.18	- 47.87	13.26
Boiling point (^0C, 1 Atm)	110.6	136.25	144.4	139.1	138.5
Density ($g{\cdot}cm^{-1}$@ 20 ^0C)	0.8669	0.867	0.8802	0.8642	0.8611
Flash point (^0C)	4.4	18.0	17.0	25.0	25.0
Vapour pressure (kPa @ 25^0C)	3.74-4.0	1.276	8.80-8.92	11.00-11.66	11.60-11.80
Henry's law constant ($Pa{\cdot}m^3{\cdot}mole^{-1}$)	518-682	669-1001	436-594	506-1115	506-879
Solubility ($mg{\cdot}L^{-1}$ @ 25 ^0C)	347-707	150	170-221	122-223	150-215
Half-life (h) in					
Air	2.4 -104	0.24-85.6	0.24-44	83-26	0.24-42
Water	5.5-528	5-240	5.8-672	168-672	168-672
Soil	96-528	72-240	168-672	168-172	168-672
Log K_{oc}	1.89-2.58	1.98-3.04	1.63-2.73	2.04-3.13	2.05-3.08
Log K_{ow}	2.11-3.0	3.13-3.43	3.08-3.29	3.20-3.29	3.09-3.18
Log BCF	0.22-3.28	0.67-2.67	0.79-2.34	0.78-2.40	1.17-2.41

BCF = bioconcentration factor

Table source: Mackay et al. (1992)

APPENDIX II. DETECTION LIMITS AND ACCURACY OF ANALYTICAL METHODS 8240B AND 8260A FOR TEX IN SOILS

	Method 8240B			Method 8260A		
TEX	Detection limit ($\mu g \cdot kg^{-1}$)	Range ($\mu g \cdot kg^{-1}$)	Accuracy ($\mu g \cdot kg^{-1}$)	Detection limit ($\mu g \cdot L^{-1}$)	Range ($\mu g \cdot L^{-1}$)	Mean accuracy (% of true value)
Toluene	5	5 - 600	0.98±2.03	0.5	0.5 - 10	102
Ethylbenzene	5	5 - 600	0.98±2.48	0.1	0.1 - 10	99
o-xylene	---	---	---	0.1	0.1 - 31	103
m-xylene	---	---	---	0.1	0.1 - 10	97
p-xylene	---	---	---	0.5	0.5 - 10	104
Xylenes (Total)	5	5 - 600	---	---	---	---

Source: CCME 1993

APPENDIX III. PRODUCTION CAPACITY AND SUPPLY (KILOTONNES) OF TOLUENE AND XYLENES IN CANADA

		1986	**1987**	**1988**	**1989**	**1990**	**1993**
Toluene	Capacity	580	630	630	630	630	595
	Supply	426.6	446	490.7	483	NA	540
Xylenes	Capacity	460	495	495	495	790	790
	Supply	376.5	351	405	439.5	518.5	623

NA = not available

Source = CIS 1991

[1] forecast from Corpus Information Service (CIS 1989, 1991)

APPENDIX IV. CONCENTRATIONS OF TEX COMPOUNDS IN THE CANADIAN ENVIRONMENT

Environment	Toluene	Ethyl-benzene	Xylenes	Remarks	Reference
Soil (mg·kg^{-1})	0.0013 0.00092	0.00046 0.00040	0.00092 0.00080	rural parkland old urban parkland	OMEE 1993[a]
Air (μg·m^{3})	202 in 1985 535 in 1986	—	221 (winter) 85 (summer)	gas stations across Canada	PACE 1987, 1989
	1900 (winter) 2600 (summer)	—	716 (winter) 973 (summer)	self-service gas stations	PACE 1987, 1989
	5 to 44 (urban) 1.1 (rural)	—	—	Ontario, 1983 to 1989	Dann et al. 1989
	—	—	0.4 to 34 0.3 to 2.5	urban Ontario rural Ontario	Dann and Wang 1992
	—	—	2 to 22000	Quebec, landfill	Dann and Gonthier 1986
Water (μg·L^{-1})	0.1 to 131 (sewage)	0.38 to 1.09	0.32 to 1.72	across Canada	NAQUADAT 1992
	0.5 (spring) 0.3 (summer) 0.1 (winter)	—	—	Great Lakes, Ontario, 1982 to 1983,	Otson 1987
	0.4	—	—	St.Clair River, 1985	Comba and Kaiser 1987
	0.59 2.08 (max)	—	—	refinery effluents, Ontario	OMOE 1989
	<0.2 to 730	<0.2 to 74	<0.2 to 191 (*p*- and *m*-) <0.2 to 123 (*o*-)	groundwater (landfills), Ontario	Baeker 1987
	295	—	—	groundwater, Ontario	Slaine and Barker 1990
	3900	—	—	shallow aquifer chemical waste disposal site	Lesage et al. 1990
	2800	—	—	liquid waste disposal site, Quebec groundwater	Pakdel et al. 1992
	—	—	52 *o*-xylene 110 *m*-and *p*-xylene	pulp effluent, Ontario	OMOE 1992
	—		37 *o*-xylene, 1417 *m*-and *p*- xylene	sludge, Ontario	OMOE 1992
	—	5 to 10	—	treated water, across Canada	Otson et al. 1982
	—	0.1 14 to 480	—	background concentration Ontario landfill	Reinhard et al. 1984

[a] These values represent the 97.5 percentile of the data distribution.

APPENDIX V. EXISTING SOIL QUALITY GUIDELINES AND CRITERIA FOR TEX IN CANADA, USA AND NETHERLANDS

Jurisdiction	Guideline/Criterion	Toluene $mg \cdot kg^{-1}$	Ethylbenzene $mg \cdot kg^{-1}$	Xylenes $mg \cdot kg^{-1}$	Reference
Canada (CCME)	Interim Assessment Criteria	0.1	0.1	0.1	CCME 1991a
	Interim Remediation Criteria:				
	Agricultural	0.1	0.1	0.1	
	Residential/Park Land	3.0	5.0	5.0	
	Commercial/Industrial	30	50	50	
Alberta	Assessment Criteria:				CCME 1991b
	Tier I	1.0	0.5	1.0	
	Tier II: Site Specific				
	Level I (High Sensitive Site)	1.0	0.5	1.0	Alberta MUST 1991 (under revision)
	Level II (Medium Sensitive Site)	10	5.0	5.0	
	Level III (low Sensitive Site)	100	100	50	
British Columbia	Level A (Background Level)	0.1	0.1	0.1	BCMOE 1989
	Level B (Remediation Criteria, Agricultural, Residential/Parklands)	3.0	5.0	5.0	
	Level C (Commercia/Industrial Lands)	30	50	50	
Manitoba	High risk (High Sensitive Site)	0.1	0.1	0.1	Manitoba Environment 1992
	Medium risk (Medium Sensitive Site)	3.0	5.0	5.0	
	Low risk (low Sensitive Site)	30	50	50	
New Brunswick	Level I (Potential to contaminate water)	3.0	5.0	5.0	New Brunswick DOE 1992
	Level II (Not covered in Level I)	30	50	50	
Nova Scotia	Level I - Total BTEX[1]	1.0	1.0	1.0	CCME, 1991b
	Level II - Total BTEX	2.0	2.0	2.0	
	Level III - Total BTEX	200	200	200	
	Surface soil with potable groundwater situation (pH 5 to 9):				OMEE 1994
Ontario (proposed clean-up guidelines)	Agricultural	1	0.5	1	
	Residential/Park Land	1	0.5	1	
	Commercial/Industrial	1	0.5	1	
	Surface soil with non-potable groundwater situation (pH 5 to 9):				OMEE 1994
	Residential/Park Land	1	0.5	1	
	Commercial/Industrial	10	5.0	5	
	Sub-surface soil with potable groundwater situation (pH 5 to 11):				OMEE 1994
	Residential/Park Land	1	0.5	1	
	Commercial/Industrial	1	0.5	1	
	Sub-surface soil with non-potable groundwater situation (pH 5 to 11):				OMEE 1994
	Residential/Park Land	10	5	5	
	Commercial/Industrial	100	100	50	

Appendix V (continued)

Jurisdiction	Guideline/Criterion	Toluene mg·kg^{-1}	Ethylbenzene mg·kg^{-1}	Xylenes mg·kg^{-1}	Reference
Prince Edward Island	Level I - Total BTEX	ND	ND	ND	CCME 1991b
	Level II - Total BTEX	2.0	2.0	2.0	
Quebec	Level A (Background Level)	0.1	0.1	0.1	MENVIQ 1988
	Level B (Remediation Criteria)	3.0	5.0	5.0	
	Level C (Immediate Clean-up)	30	50	50	
Saskatchewan	Level I (Agricultural/ Residential lands)	1.0	0.5	1.0	SEPS 1990
	Level II (Commercial/Industrial lands)	10	5.0	5.0	
California	Maximum Allowable Limits	0.3-50	1-50	1-50	OMOE 1992
Illinois	Soil Objective (BTEX)	11.7	11.7	11.7	CCME 1991b
Kansas	Remediation Level (BTEX)	100	100	100	CCME 1991b
Massachussets[2]	Soil Standard for S-1 (accessible soil used for growing fruits or vegetables for humans, or high frequency or intensity of use by children or adults)	100	100	100	MDEP 1993
	GW-1	8	80	100	
	GW-2	8	100	100	
	GW-3	8	100	100	
	Soil Standard for S-2 (accessible soil of low use and intensity of activity)	2500	2500	2500	MDEP 1993
	GW-1	90	80	830	
	GW-2	510	2500	460	
	GW-3	2500	500	2500	
	Soil Standard for S-3 (accessible soil which children are unlikely to visit)	5000	5000	5000	MDEP 1993
	GW-1	90	80	830	
	GW-2	510	3300	460	
	GW-3	4300	500	4100	
Michigan	Soil level	0.8	0.6	0.4	CCME 1991b
New Hampshire	Soil level (BTEX)	1.0	1.0	1.0	CCME 1991b
New York	Soil Guidance Value	0.375	0.15	0.03	CCME 1991b
Washington	Soil Action Level	0.04	0.02	0.02	CCME 1991b
The Netherlands	Target value	0.05	0.05	0.05	MHSPE 1994
	Intervention value	130	50	25	

[1] BTEX : benzene, toluene, ethylbenzene, xylenes

[2] GW-1 : groundwater is a current or potential source of drinking water

GW-2 : oil or hazardous material in groundwater may likely act as a source of vapour infiltration to occupied buildings

GW-3 : groundwater discharges to surface water.

APPENDIX VI. CONSULTED DATA ON THE EFFECTS OF TOLUENE ON TERRESTRIAL PLANTS AND INVERTEBRATES

Species	Effect (exposure period)	Endpoint	Concentration of toluene[a] (mg·kg^{-1})	Soil pH	Test substrate	Extraction method	Reference
Radish *(Raphanus sativus)*	Seedling emergence (72 hours)	NOEC LOEC EC_{25} EC_{50}	6[b] (68)[b] 12[b] (271)[b] 7[b] (406)[b] 84[b] (119)[b]	4 - 4.5	Artificial soil (20% kaolinite clay, 10% peat, 70% silica sand)	EPA SW846, 3810/8015 and 8020.	Environment Canada 1995
Lettuce *(Lactuca sativa)*	Seedling emergence (120 hours)	NOEC LOEC EC_{25} EC_{50}	7 (135) 17 (271) 9 (162) 12 (198)				Environment Canada 1995
Radish *(Raphanus sativus)*	Root elongation (72 hours)	NOEC LOEC EC_{25} EC_{50}	6 (102) 15 (203) 11 (162) 22 (284)				Environment Canada 1995
Lettuce *(Lactuca sativa)*	Root elongation (120 hours)	NOEC LOEC EC_{25} EC_{50}	4 (68) 7 (136) 5 (82) 7 (133)				Environment Canada 1995
Earthworm *(Eisenia foetida)*	Mortality (7 days)	NOEC LOEC LC_{25} LC_{50}	34 (338) 71 (678) 44 (463) 126 (678)				Environment Canada 1995
Earthworm *(Eisenia foetida)*	Mortality (14 days) (28 days) (28 days) Cocoon prod. (28 d) Worms appearance (fat dissolution and cell membrane damage) (28 d)	LC_{50} LC_{50} NOEC NOEC NOEC	(100-180) (100-180) (100-180) (32-100) (10-32)	6	Artificial soil (sand, peat and kaoline), moisture 55 %	Nominal	Vonk *et al.* 1986
Earthworm *(Eisenia foetida)*	Reduced growth Mortality (2 to 6 weeks)	EC EC (100%)	(500 mg·kg^{-1} bw·d^{-1}) (2000 mg·kg^{-1} bw·d^{-1}) [calculated dose]	---	30 g sludge on 4 cm of silt loam	Nominal	Hartenstein 1982
Earthworm *(Eisenia foetida)*	Mortality Cocoon production Visual conditions (2 week)	NOEC NOEC NOEC	(150 to 280) (150 to 250) (15 to 50)	---	Artificial soil	Nominal	Slooff and Blokzijl 1988
Earthworm *(Eisenia foetida)*	Mortality (48 hours)	LC_{50}	(75 µg·cm^{-2})	---	Filter paper	Nominal	Neuhauser *et al.* 1985

[a] Values in parenthesis are nominal concentrations

[b] Value from only one replicate

APPENDIX VII. CONSULTED DATA ON THE EFFECTS OF TOLUENE ON MAMMALS

Species	Effect	Endpoint	Concentration of toluene	Dose of toluene	Exposure period (exposure route)	Reference
Rat	Mortality	LD_{30}	---	2.5 $g \cdot kg^{-1}$ bw	single dose (oral)	Gerarde 1959
Rat (young adult)	Mortality	LD_{50}	---	5.55 $g \cdot kg^{-1}$ bw	single dose	Kimura et al. 1971
Rat (young adult)	Mortality	LD_{50}	---	6.6 $g \cdot kg^{-1}$ bw	single dose (oral)	Smyth Jr. et al. 1969
Rat (14 d old)	Mortality	LD_{50}	---	2.6 $g \cdot kg^{-1}$ bw	single dose (oral)	Kimura et al. 1971
Rat	Mortality	LC_{50}	8800 ppm	---	4 hours (inhalation)	Carpenter et al.1976
Rat	Decreased avoidance response Extreme excitation Slight ataxia	EC EC EC	125 ppm 2000 ppm 4000 ppm	---	4 hours (inhalation)	Kishi et al. 1988
Rat	Decreased lung cytochrome P-450	EC	---	1 $g \cdot kg^{-1}$ bw	single dose (i.p.)	Furman et al. 1991
Rabbit	Mortality	LD_{50}	---	14 $g \cdot kg^{-1}$ bw	single dose (dermal)	Union Carbide 1976
Rat (female)	---	NOAEL	---	590 $mg \cdot kg^{-1}$ $bw \cdot d^{-1}$	193 days (oral)	Wolf et al. 1956
Rat	Decreased growth, induced MFO activity ---	EC NOAEL	---	100 $mg \cdot kg^{-1}$ $bw \cdot d^{-1}$ 50 $mg \cdot kg^{-1}$ $bw \cdot d^{-1}$	14 days (oral)	Kom 'a et al. 1989
Rat, guinea pig, dog, primate	Body weight, histopathological or hematologic effects	NOEC	389 $mg \cdot m^{-3}$	---	90 d, continuous (inhalation)	Jenkins et al. 1970
Rat, dog	Significantly different effects	NOEC	3.9 $mg \cdot L^{-1}$ $6h \cdot d^{-1}$	---	13 weeks (inhalation)	Carpenter et al. 1976
Rat	Inhibition of phagocytic activity of leucocytes	EC	390 ppm $4h \cdot d^{-1}$	---	6 months (inhalation)	Bernshtein 1972
Rat (male)	Increased adrenal weight and plasma hydrocorticoids decreased eosinophiles	EC	1000 ppm $8h \cdot d^{-1}$	---	4 weeks (inhalation)	Takevchi et al. 1979
Rat	Decreased serum albumin increased beta- and gama-globulin and lipoprotein levels	EC	6450 ppm $5h \cdot d^{-1}$	---	4 months (inhalation)	Mackshanova and Omelyanchik 1977
Mouse	Motor activity increase	LOAEL NOAEL	560 ppm 300 ppm	---	1 $h \cdot d^{-1}$, 2 $d \cdot w^{-1}$ for 3 weeks (inhalation)	Wood and Colotla 1990
Rat	Locomotor activity	NOAEL	80 ppm	---	6 $h \cdot d^{-1}$ for 3 days (inhalation)	von Euler et al. 1991
Rat	Behaviour, kidney, liver some biochemical changes	NOAEL	1500 ppm	---	6 $h \cdot d^{-1}$, 5 $d \cdot w^{-1}$ for 6 months (inhalation)	Ladefoged et al. 199

APPENDIX VIII. CONSULTED DATA ON THE EFFECTS OF ETHYLBENZENE ON TERRESTRIAL PLANTS AND INVERTEBRATES

Species	Effect	Endpoint	Concentration of ethylbenzene[a] (mg·kg^{-1})	Soil pH	Test substrate	Extraction method	Reference
Radish (*Raphanus sativus*)	Seedling emergence (72 hours)	NOEC LOEC EC_{25} EC_{50}	9 (42) 20 (84) 12 (53) 16 (68)	4 - 4.5	Artificial soil (20% kaolinite clay, 10% peat, 70% silica sand)	EPA Method SW846, 3810/8015 and 8020	Environment Canada 1995
Lettuce (*Lactuca sativa*)	Seedling emergence (120 hours)	NOEC LOEC EC_{25} EC_{50}	5[b] (34)[b] 9 (42) 6 (30) 9 (43)				Environment Canada 1995
Radish (*Raphanus sativus*)	Root elongation (72 hours)	NOEC LOEC EC_{25} EC_{50}	16 (68) 34 (135) 31 (122) 71 (217)				Environment Canada 1995
Lettuce (*Lactuca sativa*)	Root elongation (120 hours)	NOEC LOEC EC_{25} EC_{50}	12 (51) 25 (102) 15 (61) 23 (94)				Environment Canada 1995
Earthworm (*Eisenia foetida*)	Mortality (7 days)	NOEC LOEC LC_{25} LC_{50}	73 (203) 192 (406) 113 (288) 155 (377)				Environment Canada 1995
Earthworm (*Eisenia foetida*)	Mortality (48 hours)	LC_{50}	47 µg·cm^{-2}	—	Filter paper (contact test)	—	Neuhauser et al. 1985

[a] Values in parenthesis are nominal concentrations

[b] Values from only one replicate

APPENDIX IX. CONSULTED DATA ON THE EFFECTS OF ETHYLBENZENE ON MAMMALS

Species	Effect	Endpoint	Concentration of ethylbenzene	Dose of ethylbenzene	Exposure Period (exposure route)	Reference
Rat	Mortality	EC (70%)	---	$2.7\ g\cdot kg^{-1}$	single dose (oral)	Gerarde 1959
Rat	Mortality	LD_{50}	---	$3.5\ g\cdot kg^{-1}$	single dose (oral)	Wolf et al. 1956
Rat	Mortality	LD_{50}	---	$4.7\ g\cdot kg^{-1}$	single dose (oral)	Smyth Jr. et al. 1962
Rabbit	Mortality	LD_{50}	---	$15.4\ g\cdot kg^{-1}$	single dose (dermal)	Smyth Jr. et al. 1962
Rabbit	Mortality	LD_{50}	---	$> 5\ g\cdot kg^{-1}$	single dose (dermal)	Opdyke 1975
Rat	Destructive to pulmonary cytochrome P_{450}	EC	---	$0.53\ g\cdot kg^{-1}$	single dose (i.p.)	Pyykkö et al. 1987
Rat	Increased liver & kidney weights	NOAEL EC	---	$136\ mg\cdot kg^{-1}\cdot d^{-1}$ $408\ mg\cdot kg^{-1}\cdot d^{-1}$	5 days a week for 6 months (oral)	Wolf et al. 1956
Rabbit	Changes in blood and plasma globulins liver ,kidney and muscle weights	EC	$230\ ppm\cdot h^{-1}\cdot d^{-1}$	---	7 months (inhalation)	US EPA 1980
Rat	Growth depression increase in liver and kidney weights	EC	2200 ppm $7\ h\cdot d^{-1}$, $5d\cdot w^{-1}$	---	144 days total 103 exposures total (inhalation)	Wolf et al. 1956
Rat	Increase in liver and kidney weights	EC (slight)	1250 ppm $7h\cdot d^{-1}$, $5d\cdot w^{-1}$	---	214 days total 138 exposure days (inhalation)	Wolf et al. 1956
Guinea pig	---	NOEC	400 ppm $7h\cdot d^{-1}$, $5d\cdot w^{-1}$	---	186 days total 130 exposure days (inhalation)	Wolf et al. 1956
Rat Mice	---	NOAEL LOAEL	382 ppm 782 ppm	---	$6\ h\cdot d^{-1}$, $5\ d\cdot w^{-1}$ for 4 weeks (inhalation)	Cragg et al. 1989
Rabbit	---	NOAEL LOAEL	782 ppm 1610 ppm	---	$6\ h\cdot d^{-1}$, $5\ d\cdot w^{-1}$ for 4 weeks (inhalation)	Cragg et al. 1989

APPENDIX X. CONSULTED DATA ON THE EFFECTS OF XYLENES ON TERRESTRIAL PLANTS AND INVERTEBRATES

Species	Effect	Endpoint	Concentration of xylenes[a] ($mg \cdot kg^{-1}$)	Soil pH	Test substrate	Analytical method	Reference
Radish (*Raphanus sativus*)	Seedling emergence (72 hours)	NOEC LOEC EC_{25} EC_{50}	1.4 (104) 33 (206) 32 (178) 97 (291)	4 - 4.5	Artificial soil (20% kaolinite clay, 10% peat, 70% silica sand)	EPA Method SW846, 3810/8015 and 8020	Environment Canada 1995
Lettuce (*Lactuca sativa*)	Seedling emergence (120 hours)	NOEC LOEC EC_{25} EC_{50}	0.6 (52) 19 (104) 5 (81) 13 (132)				Environment Canada 1995
Radish (*Raphanus sativus*)	Root elongation (72 hours)	NOEC LOEC EC_{25} EC_{50}	0.43 (21) 0.76 (43) 0.65 (36) 28 (180)				Environment Canada 1995
Lettuce (*Lactuca sativa*)	Root elongation (120 hours)	NOEC LOEC EC_{25} EC_{50}	0.26 (17) 0.52 (34) 0.34 (24) 9 (66)				Environment Canada 1995
Corn (*Zea mays L*)	Germination, seedling development and dry weight (8 hours)	EC (significant reduction)	Seeds soaked in pure xylene	---	---	---	Hung et al. 1992
Earthworm (*Eisenia foetida*)	Mortality (7 days)	NOEC LOEC LC_{25} LC_{50}	33 (206) 124 (412) 56 (258) 79 (309)	4 - 4.5	Artificial soil (20% kaolinite clay, 10% peat, 70% silica sand)	EPA Method SW846, 3810/8015 and 8020	Environment Canada 1995

[a] Values in parentheses are nominal concentrations

APPENDIX XI. CONSULTED DATA ON THE EFFECTS OF XYLENES ON MAMMALS

Species	Effect	Endpoint	Concentration of xylenes	Dose of xylenes	Form of xylenes	Exposure period (exposure route)	Reference
Rat	Mortality	LD_{50}	---	4300 $mg \cdot kg^{-1}$	mixed	single dose (oral)	Wolf et al. 1956
Rat	Mortality	LD_{50}	---	5800 $mg \cdot kg^{-1}$	mixed	single dose (oral)	Ungvary 1979
Rat	Mortality (7 of 10 died)	LD_{70}	---	4401 $mg \cdot kg^{-1}$	*o*-xylene	single dose (oral)	Gerarde 1959
	Mortality (3 of 10 died)	LD_{30}	---	4421 $mg \cdot kg^{-1}$	*m*-xylene	single dose (oral)	Gerarde 1959
	Mortality (6 of 10 died)	LD_{60}	---	4306 $mg \cdot kg^{-1}$	*p*-xylene	single dose (oral)	Gerarde 1959
Rat - male	Mortality	LC_{50}	6700 ppm	---	mixed with EB 19.3%	4 hours (inhalation)	Carpenter et al. 1975
Rat - female	Mortality	LC_{50}	6350 ppm	---	mixed with EB 19.3%	4 hours (inhalation)	Hine et al. 1970
Rat	Liver damage	NOAEL	1600 ppm	---	*p*-xylene	6 $h \cdot d^{-1}$ for 1-3 days (inhalation)	Simmons et al. 1991
	Increased liver cytochrome P-450	LOAEL	1600 ppm	---			
Rat	Chemical changes in the liver	EC	---	864 $mg \cdot kg^{-1}$	*m*-xylene	once a day for 3 days (oral)	Raunio et al. 1990
Rat	Coordination & irritation of mucous membranes decreased white cell Count 2 out of 4 died	EC	1600 ppm	---	mixed	18-20 $h \cdot d^{-1}$ up to 4 days (inhalation)	NAS 1977
Guinea pig	Liver and lung effects	EC (slight)	300 ppm	---	mixed	4 $h \cdot d^{-1}$, 6 $d \cdot w^{-1}$ for 2 months (inhalation)	NAS 1977

Appendix XI (continued)

Species	Effect	Endpoint	Concentration of xylenes	Dose of xylenes	Form of xylenes	Exposure period (exposure route)	Reference
Rabbit	Decrease red and white blood cell count	EC	1150 ppm	---	benzene free xylene	40-55 days (inhalation)	NAS 1977
Mice	Mortality	EC (100%)	---	4.8 $mL \cdot kg^{-1} \cdot d^{-1}$	mixed	days 6 to 15 of gestation (oral)	Marks et al. 1982
	Mortality teratogenic effects	EC (31%) EC		3.6 $mL \cdot kg^{-1} \cdot d^{-1}$ 2.4 $mL \cdot kg^{-1} \cdot d^{-1}$		(gavage)	Marks et al. 1982
Rat & rabbit	Conjunctivic, anorexia, weight loss, drowsiness, equilibrium disturbances, some paralysis of the hind extremities	EC	1133 ppm	---	mixed	6 $h \cdot d^{-1}$, 6 $d \cdot w^{-1}$ for 130 days (inhalation)	Fabre et al. 1960
Rat & rabbit	Peripheral blood	NOAEL	690 ppm	---	mixed	8 $h \cdot d^{-1}$, 6 $d \cdot w^{-1}$ for 130 days (inhalation)	ACGIH 1980
Rat	Mortality	LD_{50}	11000 ppm	---	mixed	92 min (inhalation)	Carpenter et al. 1975
Mouse	Hematologic and immunologic changes	EC	11.5 ppm	---	mixed	4 $h \cdot d^{-1}$ for 12 months (inhalation)	Kashin et al. 1968
	Hematologic and immunologic changes	EC	46.4 ppm	---	mixed	2 $h \cdot d^{-1}$ for 12 months (inhalation)	
Rat	Decreased lung cytochrome P-450	LOAEL	75 ppm	---	*m*-xylene	24 hours (inhalation)	Elovaara et al. 1987
Rat	Biochemical changes in the liver	EC	300 ppm	---	*m*-xylene	6 hours (inhalation)	Liira et al. 1991
Rat	Altered function in the formation, secretion and transport of neurosecretory substances and of the hypothalmic-pituitary function	EC	---	200 $mg \cdot kg^{-1}$	mixed	4 months (subcutaneous)	Bakhtizina 1976

APPENDIX XII. SELECTED STUDIES ON THE TOXICITY OF TOLUENE TO TERRESTRIAL PLANTS AND SOIL INVERTEBRATES

Organism	Effect	Endpoint	Effect concentration (mg·kg^{-1})	Test substrate (exposure period)	Reference
Northern wheatgrass (*Agropyron dasystachyum*)	Shoot length	IC_{25}	525	Coarse, artificial sandy loam soil (14 d)	ESG 2002b
	Shoot wet mass	IC_{25}	255		
	Shoot dry mass	IC_{25}	242		
	Root length	IC_{25}	157		
	Root wet mass	IC_{25}	68		
	Root dry mass	IC_{25}	55		
Northern wheatgrass (*Agropyron dasystachyum*)	Shoot length	IC_{25}	991	Fine, field-collected clay loam soil (14 d)	Komex 2002 (based on data from ESG 2002b)
	Shoot wet mass	IC_{25}	590		
	Shoot dry mass	IC_{25}	620		
	Root length	IC_{25}	236		
	Root wet mass	IC_{25}	112		
	Root dry mass	IC_{25}	558		
Alfalfa (*Medicago sativa*)	Shoot length	IC_{25}	396	Coarse, artificial sandy loam soil (14 d)	ESG 2002b
	Shoot wet mass	IC_{25}	456		
	Shoot dry mass	IC_{25}	234		
	Root length	IC_{25}	253		
	Root wet mass	IC_{25}	538		
	Root dry mass	IC_{25}	305		
Alfalfa (*Medicago sativa*)	Shoot length	IC_{25}	377	Fine, field-collected clay loam soil (14 d)	Komex 2002 (based on data from ESG 2002b)
	Shoot wet mass	IC_{25}	342		
	Shoot dry mass	IC_{25}	120		
	Root length	IC_{25}	148		
	Root wet mass	IC_{25}	517		
	Root dry mass	IC_{25}	159		
Collembolan (*Onychiurus folsomi*)	Mortality	LC_{25}	521	Coarse, artificial sandy loam soil (14 d)	ESG 2002b
		NOEC	1,011		
		LOEC	1,695		
Collembolan (*Onychiurus folsomi*)	Mortality	LC_{25}	406	Fine, field-collected clay loam soil (14 d)	Komex 2002 (based on data from ESG 2002b)
Earthworm (*Eisenia andrei*)	Mortality	NOEC	80	Coarse, artificial sandy loam soil (14 d)	ESG 2002b
		LOEC	172		
Earthworm (*Eisenia andrei*)	Mortality	NOEC	172	Fine, field-collected clay loam soil (14 d)	Komex 2002 (based on data from ESG 2002b)
		LOEC	368		

APPENDIX XIII. SELECTED STUDIES ON THE TOXICITY OF ETHYLBENZENE TO TERRESTRIAL PLANTS AND SOIL INVERTEBRATES

Organism	Effect	Endpoint	Effect concentration ($mg \cdot kg^{-1}$)	Test substrate (exposure period)	Reference
Northern wheatgrass (*Agropyron dasystachyum*)	Shoot length	IC_{25}	870	Coarse, artificial sandy loam soil (14 d)	ESG 2002b
	Shoot wet mass	IC_{25}	88		
	Shoot dry mass	IC_{25}	150		
	Root length	IC_{25}	274		
	Root wet mass	IC_{25}	3		
	Root dry mass	IC_{25}	112		
Northern wheatgrass (*Agropyron dasystachyum*)	Shoot length	IC_{25}	2,416	Fine, field-collected clay loam soil (14 d)	Komex 2002 (based on data from ESG 2002b)
	Shoot wet mass	IC_{25}	463		
	Shoot dry mass	IC_{25}	664		
	Root length	IC_{25}	652		
	Root wet mass	IC_{25}	218		
	Root dry mass	IC_{25}	545		
Alfalfa (*Medicago sativa*)	Shoot length	IC_{25}	1,178	Coarse, artificial sandy loam soil (14 d)	ESG 2002
	Shoot wet mass	IC_{25}	754		
	Shoot dry mass	IC_{25}	506		
	Root length	IC_{25}	462		
	Root wet mass	IC_{25}	752		
	Root dry mass	IC_{25}	560		
Alfalfa (*Medicago sativa*)	Shoot length	IC_{25}	503	Fine, field-collected clay loam soil (14 d)	Komex 2002 (based on data from ESG 2002b)
	Shoot wet mass	IC_{25}	726		
	Shoot dry mass	IC_{25}	321		
	Root length	IC_{25}	316		
	Root wet mass	IC_{25}	543		
	Root dry mass	IC_{25}	372		
Collembolan (*Onychiurus folsomi*)	Mortality	LC_{25}	576	Coarse, artificial sandy loam soil (14 d)	ESG 2002b
		NOEC	594		
		LOEC	967		
Collembolan (*Onychiurus folsomi*)	Mortality	LC_{25}	259	Fine, field-collected clay loam soil (14 d)	Komex 2002 (based on data from ESG 2002b)
Earthworm (*Eisenia andrei*)	Mortality	NOEC	16	Coarse, artificial sandy loam soil (14 d)	ESG 2002b
		LOEC	112		
Earthworm (*Eisenia andrei*)	Mortality	NOEC	16	Fine, field-collected clay loam soil (14 d)	Komex 2002 (based on data from ESG 2002b)
		LOEC	112		

APPENDIX XIV. SELECTED STUDIES ON THE TOXICITY OF XYLENES TO TERRESTRIAL PLANTS AND SOIL INVERTEBRATES

Organism	Effect	Endpoint	Effect concentration ($mg \cdot kg^{-1}$)	Test substrate (exposure period)	Reference
Northern wheatgrass (*Agropyron dasystachyum*)	Shoot length	IC_{25}	430	Coarse, artificial sandy loam soil (14 d)	ESG 2002b
	Shoot wet mass	IC_{25}	137		
	Shoot dry mass	IC_{25}	167		
	Root length	IC_{25}	608		
	Root wet mass	IC_{25}	90		
	Root dry mass	IC_{25}	196		
Northern wheatgrass (*Agropyron dasystachyum*)	Shoot length	IC_{25}	443	Fine, field-collected clay loam soil (14 d)	Komex 2002 (based on data from ESG 2002b)
	Shoot wet mass	IC_{25}	396		
	Shoot dry mass	IC_{25}	367		
	Root length	IC_{25}	241		
	Root wet mass	IC_{25}	367		
	Root dry mass	IC_{25}	282		
Alfalfa (*Medicago sativa*)	Shoot length	IC_{25}	1,200	Coarse, artificial sandy loam soil (14 d)	ESG 2002b
	Shoot wet mass	IC_{25}	558		
	Shoot dry mass	IC_{25}	421		
	Root length	IC_{25}	480		
	Root wet mass	IC_{25}	612		
	Root dry mass	IC_{25}	442		
Alfalfa (*Medicago sativa*)	Shoot length	IC_{25}	593	Fine, field-collected clay loam soil (14 d)	Komex 2002 (based on data from ESG 2002b)
	Shoot wet mass	IC_{25}	178		
	Shoot dry mass	IC_{25}	92		
	Root length	IC_{25}	101		
	Root wet mass	IC_{25}	130		
	Root dry mass	IC_{25}	111		
Collembolan (*Onychiurus folsomi*)	Mortality	LC_{25}	733	Coarse, artificial sandy loam soil (14 d)	ESG 2002
		NOEC	540		
		LOEC	951		
Collembolan (*Onychiurus folsomi*)	Mortality	LC_{25}	835	Fine, field-collected clay loam soil (14 d)	Komex 2002b (based on data from ESG 2002b)
Earthworm (*Eisenia andrei*)	Mortality	NOEC	8	Coarse, artificial sandy loam soil (14 d)	ESG 2002b
		LOEC	78		
Earthworm (*Eisenia andrei*)	Mortality	NOEC	8	Fine, field-collected clay loam soil (14 d)	Komex 2002 (based on data from ESG 2002b)
		LOEC	78		

XV. PARAMETERS USED FOR CALCULATIONS THAT ARE NOT DEPENDENT ON CHEMICAL COMPOSITION, SOIL TYPE OR SOIL TEXTURE.

Parameter	Symbol (units)		Value	Source
Fraction of organic carbon	f_{oc} (mass/mass)		0.005	CCME 2000
Length of contaminated soil	X (m)		10	CCME 2000
Unconfined aquifer thickness	d_a (m)		5	CCME 2000
Hydraulic gradient	i		0.05	CCME 2000
Distance to receptor	x (m)		10	CCME 2000
Time since the contaminant release	t (y)		100	CCME 2000
Distance to receptor perpendicular to groundwater flow	y (m)		0	CCME 2000
Source width	Y (m)		30	CCME 2000
Depth to groundwater	d (m)		3	CCME 2000
Body weight for cattle	BW cattle (kg)		701	CCME 1999
Body weight for human	BW human (kg)	Adult	70.7	CCME 2000
		Toddler	16.5	
Drinking water ingestion rate for cattle	IR_w cattle ($L \cdot d^{-1}$)		87.5	CCME 1999
Drinking water ingestion rate for human	IR_w human ($L \cdot d^{-1}$)	Adult	1.5	CCME 2000
		Toddler	0.6	
Food ingestion rate for dairy cattle	FIR ($kg \cdot d^{-1}$)		18.5	CCME 1999
Proportion of soil ingested by dairy cattle	PSI		0.083	McMurter 1993
Soil ingestion rate for human	SIR ($g \cdot d^{-1}$)	Adult	0.02	CCME 2000
		Toddler	0.08	
Exposure term	ET Agricultural	Adult	NA	CCME 2000
		Toddler	1	
	Residential	Adult	NA	
		Toddler	1	
	Commercial	Adult	NA	
		Toddler	0.27	
	Industrial	Adult	0.27	
		Toddler	NA	
Soil allocation factor	SAF		0.5	CCME 2000
Surace area of hands	SA_{hands} (cm^2)	Adult	890	CCME 2000
		Toddler	430	
Surface area of other exposed skin	SA_{other} (cm^2)	Adult	2,500	CCME 2000
		Toddler	2,580	
Dermal soil loading for hands	DL_{hands} ($mg \cdot cm^{-1} \cdot event^{-1}$)	Adult	0.1	CCME 2000
		Toddler	0.1	

Dermal soil loading for other exposed skin	DL_{other} ($mg \cdot cm^{-1} \cdot event^{-1}$)	Adult Toddler	0.01 0.01	CCME 2000
Density of water	ρ_w ($g \cdot cm^{-3}$)		1	CCME 2000
Effective mixing depth in aquifer	B (m)		2	CCME 2000
Site length	L (m)		10	CCME 2000

APPENDIX XVI. PARAMETERS USED FOR CALCULATIONS AND THAT DIFFER BETWEEN SOIL TEXTURE. ALL DATA WERE TAKEN FROM CCME (2000).

Parameter	Symbol (units)	Coarse soil	Fine soil
Moisture-filled porosity	θ_w (vol/vol)	0.119	0.168
Vapour-filled porosity	θ_a (vol/vol)	0.281	0.132
Dry soil bulk density	ρ_b ($g \cdot cm^{-3}$)	1.7	1.4
Infiltration (recharge) rate	I ($m \cdot y^{-1}$)	0.28	0.20
Aquifer hydraulic conductivity	K ($m \cdot y^{-1}$)	320	32
Total soil porosity	θ_t (vol/vol)	0.4	0.3
Soil vapour permeability to vapour flow	k_v (cm^2)	10^{-8}	10^{-9} [a]
Soil water content	θ_m (mass/mass)	0.07	0.12

APPENDIX XVII. PARAMETERS USED FOR CALCULATIONS AND THAT DIFFER BETWEEN CHEMICAL COMPOUNDS.

Parameter	Symbol (units)	Toluene	Ethyl-benzene	Xylenes	Source
Organic carbon parition coefficient	K_{oc} ($mg \cdot L^{-1}$)	234	537	586	TPHCWG 1997
Henry's law constant	H'	0.274	0.358	0.252	TPHCWG 1997
Decay half-life of chemical in saturated	$t_{1/2s}$ (y)	0.288	0.312	0.500	BCMELP 1996
Vapour viscosity	μ ($g \cdot cm^{-1} \cdot s^{-1}$)	1.73×10^{-4}	1.73×10^{-4}	1.73×10^{-4}	CCME 2000
Absorption factor for gut	AF_G	1	1	1	*assumed*
Absorption factor for soil dermal contact	AF_D	0.12	0.2	0.12	CCME 2000
Diffusion coefficient in air	D_a ($cm^2 \cdot s^{-1}$)	0.087	0.075	0.078	TPHCWG 1997
Water quality guideline for drinking water	WQG_{DW} ($mg \cdot L^{-1}$)	0.024	0.0024	0.3	Health Canada 1996b
Water quality guideline for aquatic life	WQG_{AL} ($mg \cdot L^{-1}$)	0.002	0.090	0.180*	CCME 1999; Komex 2002
Tolerable daily intake	TDI ($mg \cdot kg^{-1}$ $bw \cdot d^{-1}$)	0.22	0.10	1.50	Health Canada 1996a; USEPA 1991
Estimated daily intake	EDI ($mg \cdot kg^{-1}$ $bw \cdot d^{-1}$)	0.0028	--	--	Health Canada 1992;
			0.0029	--	ATSDR 1999;
				0.0079	Health Canada 1993
Tolerable concentration	TC ($mg \cdot m^{-3}$)	3.8	1.0	0.18	Health Canada 1996a
Background indoor air concentration	C_a ($mg \cdot m^{-3}$)	0.0442	--	--	Health Canada 1992;
			0.0075	--	ATSDR 1999;
				0.0182	Health Canada 1993
Background soil concentration	BSC ($mg \cdot kg^{-1}$)	0	0	0	*assumed*

* Note that a Canadian Water Quality Guideline for the protection of aquatic life for xylenes does not currently exist. Therefore, for the purposes of calculating a groundwater check, an aquatic life threshold value for xylenes was estimated, as outlined in Komex (2002). This threshold value is not endorsed by the CCME Water Quality Task Group and should not be used as a water quality guideline.

APPENDIX XVIII. PARAMETERS USED FOR CALCULATIONS AND THAT ARE SPECIFIC TO LAND USE AND BUILDING STRUCTURES. ALL DATA WERE TAKEN FROM CCME (2000).

Parameter	Symbol (units)	Agricultural/Residential		Commercial/ Industrial
		basement	slab-on-grade	slab-on-grade
Distance from contaminant source to foundation	L_T (cm)			
	surface soil	30	30	30
	subsoil	30	139	139
Building length	L_B (cm)	1,225	1,225	2,000
Building width	W_B (cm)	1,225	1,225	1,500
Building height	H_B (cm)	488	488	300
Air exchanges per hour	ACH ($exch \cdot h^{-1}$)	1	1	2
Pressure differential	ΔP ($g \cdot cm^{-1} \cdot s^{-2}$)	40	40	20
Length of idealized cylinder	X_{crack} (cm)	4,900	4,900	7,000
Distance below grade to idealized cylinder	Z_{crack} (cm)	244	11.25	11.25
Radius of idealized cylinder	r_{crack} (cm)	0.203	0.203	0.264
Thickness of the foundation	L_{crack} (cm)	11.25	11.25	11.25
Effective diffusion coefficient through the crack	D_{crack} ($cm^2 \cdot s^{-1}$)	0.00790	0.00681	0.00709
Area of cracks through which contaminant vapours enter building	A_{crack} (cm^2)	995	995	1,850